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

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by

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(2018-11-028)

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2020

DECLARATION

I, hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 IN ALAPPUZHA DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "**ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 9 IN ALAPPUZHA DISTRICT OF KERALA AND GENERATION OF GIS MAPS**" is a record of research work done independently by Ms. Shamna Raju (2018-11-028) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

%	percent
ºC	degree Celsius
µg	microgram
AEU	Agro-ecologicalUnit
B	Boron
BD	Bulk density
Ca	Calcium
cm	centimetre
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

Introduction

1. INTRODUCTION

Floods are the most common and widespread of all the natural disasters which is mostly caused by high intensity precipitation that affects human life and economy (Roxy *et al.,* 2017). India is one of the highly flood prone countries of the world and flood events are becoming common in recent times. India witnessed unpredicted extreme precipitation events during 2005, 2013 and 2015 in Mumbai, Uttarakhand and Chennai resulting in flooding of large areas and claiming huge economic loss. Soil degradation due to flooding is a serious concern. Flood in Karnataka during 2009 caused an estimated loss of 287 million tons of top soil and soil nutrient loss across 10.75 million hectares of farmlands (Ramamurthy *et al.,* 2009).

In August 2018, Kerala state experienced a disastrous flood resulted out of unprecedented continuous heavy rainfall. The state received 2346.6 mm of rainfall during this period as against the normal rainfall of 1649.5 mm which was 41% more than normal. The flood and landslides caused devastating damage in the state, claiming hundreds of lives and destroying large areas of crops, even to the extent of changing the very geographical configuration of the region. The entire Kuttanad region lying in Alappuzha, Kottayam and Pathanamthitta districts was submerged up to 8 to 15 feet in the flood water for weeks. The damage caused to the ecosystem includes river bank collapse, erosion of fertile top soil, deposition of sand, silt, clay and gravel in lowlands and agricultural lands, pollution due to waste deposition, changes in water quality, soil piping and loss of vegetation.

The AEU 9 (South central laterites) in Alappuzha district which covers the eastern part of Chengannur block including Mulakkuzha, Ala, Cheriyanad, Venmoney Panchayaths and Chengannur municipality was worst affected by the 2018 flood. The rise in water level in Pamba and Manimala rivers that traverses the northern part of AEU 9 of Alappuzha district resulted in the floods which created more than 90 percent damage to this region. The soils of the South central laterites (AEU 9) are acidic, having low activity clay, often gravelly with low water and nutrient retention capacity. Major crops grown are coconut, banana, tapioca, betelvine, rubber, pepper, arecanut, paddy and vegetables such as amaranthus, brinjal, ladies finger, cowpea, cucumber, bottlegourd, snakegourd, ashgourd, chilli and tomato (KAU, 2016).

Increased temperature, altered precipitation pattern and extreme weather events associated with climate change alter soil quality. Severe soil erosion and deposition of sediments due to high intensity rainfall affects the soil quality and bring about changes in physical, chemical and biological properties. Soil quality declines due to depletion of soil organic matter, nutrient losses from runoff and leaching, desertification, accumulation of toxic substances, excessive use of chemical fertilizers and pesticide, crusting, compaction, improper waste disposal etc.

The devastating flood caused severe damage to the soil environment and agriculture. Soil fertility and productivity have been disturbed, which needs site specific investigation on soil fertility parameters. Plant nutrition needs to be relooked into and revised based on altered soil fertility status and suitable location specific management practices should be recommended. Several changes may take place when soil is under saturated condition for an extended period of time affecting physical, chemical and biological soil health. Flooded soil may experience post-flood syndrome due to water stagnation, soil erosion, nutrient depletion, deposition of sand, silt and clay etc. which needs urgent attention to restore and sustain soil productivity. Farmers should be made well aware about the changes that had occurred to the soil due to the flood and their management strategies for the effective implementation of post-flood management activities in agriculture sector. Location specific management practices should also be recommended and plant nutrition packages should be revised. A detailed study on soil quality of post-flood soils will help in formulating sustainable crop management strategies in the flood affected areas.

Therefore the present study entitled “Assessment of soil quality in the post-flood scenario of AEU 9 in Alappuzha district of Kerala and generation of GIS maps” was undertaken with the following objectives:

- To assess the soil quality in the post-flood soils of severely affected panchayats in AEU 9 of Alappuzha district of Kerala.
- To develop maps on soil characters and quality using GIS techniques
- To workout soil quality index (SQI).

Review of Literature

2. REVIEW OF LITERATURE

Assessment of soil quality is inevitable for determining the devastating impact of flooding on agricultural lands. The present study is an attempt to investigate the effect of flooding on the soil quality in the post-flood soils of AEU 9 in Alappuzha district of Kerala. The relevant literature pertaining to the present study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Alappuzha district of Kerala and generation of GIS maps" is reviewed in this chapter.

2.1 PROPERTIES OF SOILS IN AGRO ECOLOGICAL UNIT 9 (AEU 9)

The AEU 9 in Alappuzha district extends over 8058 ha (5.71%) of total area of the district covering the eastern part of Chengannur block which includes Mulakkuzha, Ala, Cheriyanad Venmony Panchayaths and Chengannur municipality. Soils of AEU 9 (South Central Laterites) are strongly acid, lateritic clay, gravelly and often underlain by plinthite. The lowlands have strongly acid, low-activity non gravelly clay soils, with impeded drainage. The climate is tropical humid monsoon type with mean annual rainfall of 2827 mm and mean annual temperature of 26.5°C. Dry period is around three and a half months (Kerala State Planning Board, 2013)

Soils of Chengannur block are poor in N, P, K and low in bases. These soils are very strongly acid to slightly acid with overall pH ranging from 4.5 to 6.5 which requires liming. Available nitrogen, phosphorous and potassium are medium, calcium is adequate and magnesium, sulphur are deficient. These soils are also deficient in boron with content less than 0.5 mg kg^{-1}. The poor status of these nutrients is due to the texture and heavy leaching of soils by rain. The organic carbon content is medium indicating medium level of plant available nitrogen (GOK, 2016)

2.2 EFFECTS OF FLOODING ON SOIL PROPERTIES

Flooding of soil results in a series of physical, chemical and biological changes that significantly influences the soil quality. The nature and extent of these changes depends on the types and properties of the soil and on the duration of submergence.

2.2.1 Effect of flooding on physical properties of soil

Submergence of soil decreases the gaseous exchange between soil and air.

Later the soil microorganisms and plant roots utilizes all the available oxygen resulting in anaerobic conditions (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. Njoku *et al.* (2011) reported that porosity, moisture content, pH and organic carbon were higher in flooded soils. Sandy loam soils are vulnerable to erosion due to its properties. During flooding, rupture of large soil aggregates takes place due to which pores become filled with dispersed clay and the permeability of soil decreases. (Kirk *et al.,* 2013).

Lack of soil aggregation affects agriculture by decreasing soil quality and productivity. The poorly formed aggregates may clog the soil pores and disintegrate the soil structure. The aggregate stability of cultivated soils is more affected by the reduced conditions than that of uncultivated soils (De Campos *et al*., 2009).

2.2.2 Effect of flooding on chemical properties of soil

Flooding of soil alters the electrochemical properties due to dilution of soil solution. Submergence increases pH and decreases electrical conductance in acidic soils whereas it decrease the soil pH in alkali soils. Reduced state of the flooded soil is shown by lower redox potential. The specific conductance of flooded soils increases during the first few weeks after flooding, reaches a peak and then declines to a stable value. Flooding increases cation exchange capacity of acidic soils. The main chemical changes includes accumulation of carbondioxide, transformation of nitrogen, reduction of iron, manganese and sulphate (Ponnamperuma, 1984).

On continuous flooding anaerobic condition develops and nitrogen transformations like ammonification, nitrate reduction, and denitrification occurs. Due to ammonification, ammoniacal nitrogen is produced and due to nitrate reduction and denitrification, nitrate nitrogen is lost (Unger *et al.,* 2009).

The primary effect in the sequence of water logging-induced processes is a reduction in the redox potential of the soil. A slight decrease in the redox potential severely affects the bacterial reduction of nitrogen to plant available forms like nitrate and ammoniacal nitrogen. The nitrate nitrogen content and ammoniacal nitrogen showed an increasing trend after flooding (Ernst, 1990).

Sah and Mikkelsen (1989) reported that flood induced P deficiency in soil is caused by high P sorptivity and lower P desorption as a consequence of Fe transformations. They also observed that the addition of organic matter at elevated temperature to flooded soils resulted in a rapid increase in P sorption.

Kalshetty *et al*. (2012) observed that there is no much changes in bulk density, texture and water holding capacity of the soil after flooding. Whereas the pH decreased and electrical conductivity increased due to the deposition of total dissolved solids. There was a lowering of nitrogen content in the flood affected soils due to the leaching of nitrate nitrogen with flooded water and denitrification due to anaerobic condition. Available potassium increased due to the swelling of clay minerals caused by water saturation and subsequent release of fixed potassium. Content of phosphorus, sulphur, calcium and magnesium increased. There was a slight elevation in iron, zinc and copper content and reduction in manganese and boron content after flood.

Akpoveta *et al*. (2014) recorded a decrease in organic carbon, pH, total nitrogen, total phosphorus and cation exchange capacity but an elevation in electrical conductivity following flooding. There was a major reduction in potassium and essential micronutrients like manganese and nickel and increased levels of heavy metals like Pb, Cd and Cu.

2.2.3 Effect of flooding on biological properties of soil

Mace *et al.* (2016) found that flood affects the soil enzyme activity by changing nutrient availability, oxygen concentration and microbial community composition. The activity of enzymes degrading lignin and cellulose increases with flooding.

Unger *et al*. (2009) reported that intermittent flooding resulted in a positive response in the amount of aerobic bacterial biomass 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..

Pedrazzini and Mckee (1984) stated that submerged soils showed 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)

2.3 CONCEPT OF SOIL QUALITY

The present concept of soil quality is developed in response to increased global emphasis on sustainable land use (Karlen *et al*., 1997). Modern definitions for soil quality are based on soil management practices, land use, ecosystem and environment interactions and socio-economic factors (Doran and Parkin, 1997). The importance of soil quality lies in attaining sustainable land use and management system, to balance productivity and environmental protection (De la Rosa and Sobral, 2008)

According to Parr *et al.* (1992), different chemical, physical, and biological properties of a soil interact in complex ways that determine its potential fitness or capacity to produce healthy and nutritious crops. The integration of these properties and resulting level of productivity often is referred to as soil quality.

Doran and Parkin (1997) defined soil quality as the capacity of a soil to function within its ecosystem boundary to sustain biological productivity, maintain environmental quality and promote plant and animal health. Karlen *et al*. (1997) suggested soil quality as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality and to support human health and habitation.

Quality of soils depends on climate, landform and most importantly, people, because it is human decisions and actions that ultimately determine whether an agricultural production system is sustainable on a given soil (Arshad and Coen, 1992). The quality and health of soil determine the agricultural sustainability and environmental quality, which jointly determine plant, animal and human health (Haberern, 1992).

Organic farming leads to higher soil quality with higher microbiological activity than conventional farming, due to versatile crop rotations, reduced application of synthetic nutrients, and the absence of pesticides (Hansen *et al.*, 2001)

The soil quality concept deviates from conventional agricultural approach focusing more on soil productivity, shifting the focus to a more holistic approach recognising the various roles played by soil in the agroecosystems and natural environment (Karlen *et al.*, 1999)

Soil Quality mainly encompasses 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 & management (Carter, 2002).

2.3.1 Soil Quality Indicators

Soil quality cannot be measured directly, but must be inferred from measuring changes in attributes of the ecosystem, referred to as indicators. Attributes that are most sensitive to management are the most desirable indicators. 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) suggested that soil quality indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions.

It is important to adopt different indicators such as physical, chemical and biological to develop soil quality. Soil organic carbon and pH are the widely used indicators. Integration of all indicators helps to develop soil quality index (SQI). It provides knowledge about soil processes and information (Zornoza *et al.*, 2015).

The selection of indicators changes according to the goal. Indicators like pH, EC, organic carbon, depth, infiltration, texture, bulk density, nutrient availability, aggregation etc. are suitable for assessing the quality of agricultural soils (Arshad and Martin, 2002).

Granatstein (1990) suggested that increased infiltration, macropores, aggregate size and stability, soil organic matter and aeration and decreased soil resistance to tillage, root penetration and decreased runoff and erosion indicates improved soil quality. Sharma and Mandal (2009) listed water logging, salinity, alkalinity and formation of acid sulphate soil as the predominant reasons of land degradation and poor 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 often referred to as soil quality. This interconnection is especially prominent between chemical and biological indicators of soil quality. (Doran and Parkin, 1994).

Universal set of indicators cannot be used for assessing soil quality as environmental conditions and soil functions differs in various locations. So different sets of indicators for soil quality are used, as the purpose of assessment varies (Bouma, 2000).

The predominant soil quality indicators at micro and macro farm scale are grouped into three sections, such as physical indicators, chemical indicators and biological indicators. Physical indicators include 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).

2.3.1.1 Physical indicators

Physical indicators give information about status of air and water in the soil such as water holding capacity and infiltration rate. It gives the capacity of soil to withstand physical forces like raindrop splashing, flooding and erosion. Physical indicators are directly related to the functions of soil. Soil texture is the most fundamental qualitative soil physical property controlling water, nutrient, and oxygen exchange, retention, and uptake. Commonly used physical indicators of soil are bulk density, particle density, water holding capacity, porosity, aggregate stability, soil texture etc (Schoenholtz *et al.*, 2000).

Soil quality can be assessed by physical parameters like soil tilth (Papendick *et al.*,1991), soil depth (Larsen and Pierce, 1991; Arshad and Coen, 1992), soil bulk density, available water holding capacity, saturated hydraulic conductivity, aggregate stability (Larsen 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).

Physical properties of the soil indicate the ability of soil to withstand physical forces of stress like splashing rain drops that lead to aggregate breakdown, soil dispersion and erosion. It also provides information on soil aeration and hydrological status (USDA, 2006).

2.3.1.2 Chemical indicators

Soil chemical attributes influence microbiological processes and chemical properties and they along with physical properties determine the capacity of soils to hold, supply and cycle nutrients and the movement and availability of water (Schoenholtz *et al*., 2000).

Chemical indicators are affected by management and natural disturbances like irrigation water, crops cultivated and fertilizer application. Reactions and processes taking place in the soil are affected by chemical components of soil. pH can control mobility and availability of micro, macro nutrients and heavy metals. Due to the association of organic carbon to mineral fraction it is also considered as a chemical indicator (USDA, 2006).

Chemical attributes like pH, EC, organic nitrogen, mineralizable nitrogen, mineral phosphorus, exchangeable potassium and organic carbon were used as basic indicators of soil quality (Larsen and Pierce, 1991; Arshad and Coen, 1992; Doran and Parkin, 1994).

2.3.1.3 Biological indicators

Biological indicators respond to both natural and human induced changes and 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 enzymes are catalyst which mediates reactions and release nutrients available to plants. Acid phosphatase is interrelated to phosphorus in soil. Acid phosphatase catalyses the breakdown of phosphate bond and releases phosphate through hydrolysis (Kumar *et al.*, 2011).

Biological indicators provides information that integrates many environmental factors with soil quality. It is an integrative indicator of the changes in the biology and biochemistry of soil resulting from external management or environmental factors (Alkotra *et al*., 2003).

Gil-Sotres *et al.* (2005) stated that the biochemical properties used to determine soil quality include microbial biomass C and activity of enzymes like dehydrogenase, phosphatase, urease and glucosidases. 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.

Farming system and fertilization affects microbial activity indicators such as acid phosphatase and dehydrogenase. Generally biological parameters are enhanced in organic farming when comparing with integrated farming system as application of manures affect soil quality positively (Flielbach *et al.*, 2007).

Soil enzymes are useful soil quality indicators due to their relationship to soil biology and are fingerprints of past soil management, and relate to soil tillage and structure (Utobo and Tewari, 2014).

2.4 CONCEPT OF MINIMUM DATA SET

The set of physical, chemical and biological indicators which shows at least 70% of variability in the total data set at each sampling site is termed as Minimum Data Set (MDS) for determining soil quality (Rezaei *et al.,* 2006).

Minimum data set provides a small subset of parameters which will make possible a more practical assessment of soil quality (Gregorich *et al*., 1994). Identifying key soil attributes that are sensitive to soil functions allows the establishment of minimum data sets. Such data sets are composed of a minimum number of soil properties that will provide a practical assessment of one or several soil processes of importance for a specific soil function (Carter, 1997).

MDS is selected based on their ability to predict soil stability and productivity. Minimum data set can be selected using principal component analysis, expert opinion methods or a combination of both (Lima *et al*., 2012). Even though PCA is widely used method, expert opinion is an easy method which simplifies indicator selection procedure (Vasu *et al*., 2016). The expert should know about the soil, crop cultivation, fertilization, and management practices done in that particular area. It leads to the development of authentic and significant soil quality index (Budak *et al.,* 2018).

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).

Larsen and Pierce (1991) used pH, EC and organic carbon as indicators in a MDS for agronomic soils. Sharma *et al*. (2012) used two sets of MDS for assessing soil quality. In rainfed pearl millet-mung bean systems the selected MDS included available N, Zn, Ca, K, pH and dehydrogenase assay while in the rainfed pearl millet alone the selected MDS included available N, Mn, exchangeable Mg, EC, dehydrogenase activity, microbial biomass carbon and bulk density.

It is necessary that the indicators which are selected for MDS should represent the functions and intricacy of the soil studied (Moncada *et al.,* 2014).

2.5 SOIL QUALITY INDEX

Parr *et al*. (1992) proposed soil quality index as SQI = f (SP, P, E, H, ER, BD, FQ, MI) where, SP is soil properties, 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 the management inputs.

Doran and Parkin (1994) developed a performance based soil quality index (SQI) which evaluates soil functions in relation to sustainable production, environmental quality and human and animal health. This index includes six elements SQE1 to SQE6. SQI = f (SQE1, SQE2, SQE3, SQE4, SQE5, SQE6) where, SQE1 is the food and fibre production, SQE2 the erosivity, SQE3 the ground water quality, SQE4 the surface water quality, SQE5 the air quality, and SQE6 is the food quality.

Andrews *et al*. (2004) developed a score based indicator set known as Soil Management Assessment Framework (SMAF). It operates in two steps viz. indicator selection and interpretation and aggregation. The indicator selection and interpretation entails the transformation of soil attributes into unitless indicator scores and aggregation combines these individual scores into a single index value (Karlen *et al*., 2008).

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

2.6 NUTRIENT INDEX

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. (Singh *et al.,* 2017).

Parker's nutrient index is a three tier system used to evaluate the fertility status of soils based on the percentage of samples in each of the three classes, that is low, medium and high and 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)

Denis *et al.* (2017) determined nutrient index with respect to soil pH, organic carbon, available P and exchangeable K to evaluate the fertility status of soils of Karnataka and estimated low nutrient index for pH and organic carbon, medium nutrient index for available phosphorus and exchangeable K.

2.7 LAND QUALITY INDEX

Land quality is the capacity of land to carry out some specific functions without deteriorating itself, which can be crop specific and location specific. The specific functions to be done by soil include food and fiber production, sustain water quality, support human and animal inhabitancy, carbon sequestration etc. (Beinroth *et al.,* 2001).

Soil organic matter is considered as an indicator of land quality as it influences soil structure and water stable aggregate formation. It increases the water holding capacity and infiltration rate of water in the soil. It acts as the store house of nutrients and reduces soil compaction through increasing aeration (Rusco *et al.*, 2001).

Kumar and Jhariya (2015) classified land quality of Chattisgarh into 4 categories namely high quality, moderate quality, marginal quality and low quality. Remote sensing and GIS techniques were used for assessing land quality incorporating analytic hierarchy process , a type of multi-criteria decision analysis method. They used ten criteria *viz.* soil organic matter content, pH, soil texture, soil depth, run off potential, geomorphology, slope, phosphorus content, potassium content and land use/ land cover to develop LQI for the area.

Natarajan *et al.* (2005) worked on assessment of land degradation and its impact on land resources of Tamil Nadu and concluded that bulk density, organic carbon and yield obtained from particular land can be considered as indicators of land quality.

Mandal *et al.* (2001) developed a crop specific LQI for sorghum in semi arid tropics of India which was closely correlated to yield and suggested that LQI is a function of climate quality index (CQI).

2.8 REMOTE SENSING, GIS AND SOIL MAPPING

Remote sensing and photogrammetric techniques provide spatially explicit, digital data representations of the earth surface that can be combined with digitized paper maps in GIS to allow efficient characterization and analysis of vast amounts of data. The main advantage of using GIS for flood management is that, it not only generates a visualization of flooding but also allows for practical estimation of the probable hazard due to flood (Sahu *et al*., 2015).

Geographic information system (GIS) is commonly used for flood mapping than remote sensing and GPS. The primary goal of GIS is to take raw data and transform it, via overlay or other analytical operations, into new information which can support decision making processes (Carter, 1997).

GIS is a powerful tool used for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). The use of GIS software can help to eliminate data integration problems caused by different geographic units related to various data sets. GIS include both manual and computer based information systems (Dickinson and Calkins, 1988). GIS enables effective and efficient manipulation of spatial and non-spatial data for scientific mapping and characterization of soils for the benefit of local people (Star *et al*., 1997).

There are various approaches for making digital soil maps based on GIS data layers. The methods used for fitting quantitative relationships between soil properties and their environment includes generalized linear models, classification and regression trees. Terrain attributes derived from digital elevation models and spectral reflectance bands of satellite imageries are commonly used (Mc Bratney *et al.,* 2003).

GIS can be used in producing soil fertility map of an area, which will help in formulating balanced fertilizer recommendation and to understand the status of soil fertility spatially and temporally (Binita *et al.,* 2009). GIS integrates spatially referenced datasets for purposes of modelling and informative decision making. It provides an innovative method for assessing land quality (Jafari and Narges, 2010).

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

Advancement in remote sensing and GIS technologies has revolutionized the gathering of information on agricultural activities including land use/land cover, weather conditions, soil conditions, etc., which are essential for site characterization and consequent assessment of land suitability for farming (Joshua *et al*., 2013).

Collection of soil samples using GPS is very important for preparing thematic soil fertility maps. A thematic map is designed to visualise a particular data or information effectively. Arc GIS tool can be used for representation of laboratory analysed data of soil quality. Generation of soil quality map involves various steps like GPS based soil sample collection, laboratory physio- chemical analysis of soil, soil quality index calculation and Arc GIS maping. The map helps to provide scientific knowledge about the quality of the soil in that particular area. Thematic maps got great significance in agriculture for future monitoring of soil nutrient status of different locations (Mishra *et al.*, 2014).

GPS records the in-field variability as geographically encoded data. It is possible to determine and record the correct position continuously (Shrestha, 2006). Information collected from different satellite data referenced with the help of GPS can be integrated to create management strategies. The development and implementation of site specific farming has been made possible by combining the GPS and GIS (Liaghat and Balasundram, 2010).

Abdel Rehman *et al*. (2018) considered the soil quality indicators like BD, Organic carbon, pH, EC, macro and micro nutrients to determine soil quality and rated the soils from low to very high soil quality using GIS based map to monitor the soil properties for efficient use of resources and concluded from the generated map that soil erosion, rainfall and salinity are the major problems in that area which reduces the soil quality.

Remote sensing and GIS technology can be used to monitor changes in soil quality. Assessment tools for indexing soil quality shows how the multiple functions like nutrient and water cycling have been used for defining quantitative relationships between soil properties and the environment (Mc Bratney *et al.*, 2003).

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Assessment of soil quality in the post flood scenario of AEU 9 in Alappuzha district of Kerala and generation of GIS maps" was carried out to assess the soil quality in flood affected soils in terms of physical, chemical and biological properties and to generate thematic maps. The methodology adopted is detailed in this chapter.

The study consisted of five parts,

Part I – Survey, collection and characterisation of soil

Part II – Setting up of MDS for the assessment of soil quality

Part III – Formulation of SQI, NI and LQI

Part IV – Generation of GIS maps

Part V – Statistical analysis

3.1. SURVEY AND COLLECTION OF SOIL

3.1.1. Details of the study area

The AEU 9 in Alappuzha district lies between 9°23'38.28" and 9°33'63.71" N latitude, 76°57'88.39" and 76°65'02.00" E longitude spread over the eastern part of Chengannur block which includes Mulakkuzha, Ala, Cheriyanad and Venmony Panchayaths and Chengannur municipality. All these panchayats selected for the present study were severely affected by flood havoc and submergence that occurred during August 2018.

The south central laterites (AEU 9) represents midland laterite terrain with typical laterite soils and short dry period. The climate is tropical humid monsoon type with mean annual temperature 26.5ºC and rainfall 2827 mm. The soils are strongly acid, lateritic clay, gravelly and often underlined by plinthite. The lowlands are strongly acidic, low activity, non-gravelly clay soils with impeded drainage conditions (KSPB, 2013). Major crops includes coconut, banana, tapioca, betelvine, rubber, pepper arecanut, paddy and vegetables (KAU, 2016).

3.1.2. Details of survey

A survey was conducted in the flood affected area of AEU 9 based on a pre designed questionnaire (Appendix I) to identify the flood affected areas, the basic details of the farmers, details of crops grown, nutrient management practices and the observable changes in soil conditions due to flooding and deposition were collected.

3.1.3. Collection of soil sample

Representative georeferenced surface soil samples were collected from seventy five sites (Table 1) in Mulakuzha, Ala, Cheriyanad, Venmony panchayats and Chengannur municipality of AEU 9 during April 2019. Field traversing was conducted in those selected areas and soil sampling sites were identified. Soil samples were taken from 0-20 cm depth from each sampling site. Core samples were also taken from the surface soils. The samples were then transferred to plastic covers and sealed. With the help of GPS, geographical coordinates of each sample site was recorded and is given in table 1. The soil sampling points of flood affected areas of AEU 9 is also depicted in the georeferenced location map of the study area (Fig 1)

Table1. Details on soil sampling locations in AEU 9 of Alappuzha district

Sl. No.	Panchayath/Municipality	No. of samples	Sampling points	N latitude	E longitude
1.	Chengannur	15	1	9.316471	76.620890
			2	9.318208	76.611337
			3	9.303914	76.628697
			4	9.310990	76.616818
			5	9.315742	76.628394
			6	9.308499	76.625713
			7	9.321199	76.632826
			8	9.333234	76.618362
			9	9.330831	76.626966
			10	9.333939	76.634122
			11	9.326585	76.629762
			12	9.324138	76.603872
			13	9.326021	76.612800
			14	9.326371	76.619240
			15	9.325189	76.620979
2.	Mulakuzha	20	16	9.300114	76.647600
			17	9.294785	76.636660
			18	9.306861	76.639335
			19	9.312741	76.638630
			20	9.299982	76.637774
			21	9.291437	76.630200
			22	9.286776	76.637001
			23	9.280624	76.637628
			24	9.280738	76.654952
			25	9.279686	76.668550
			26	9.268667	76.642124
			27	9.274741	76.653103

Table 1. Details on soil sampling locations (continued)

Sl. No	Panchayat/municipality	No. of samples	Sampling points	N latitude	E longitude
			28	9.264723	76.641468
			29	9.259652	76.639662
			30	9.272502	76.664102
			31	9.255061	76.641728
			32	9.263096	76.650738
			33	9.258337	76.648644
			34	9.267457	76.654299
			35	9.275104	76.640185
3.	Cheriyanad	19	36	9.271544	76.585784
			37	9.279365	76.588431
			38	9.264462	76.581808
			39	9.245611	76.593809
			40	9.264584	76.590965
			41	9.259999	76.586497
			42	9.250511	76.598836
			43	9.255293	76.587256
			44	9.286094	76.584668
			45	9.282198	76.594970
			46	9.280523	76.582209
			47	9.275011	76.598425
			48	9.272249	76.592694
			49	9.260402	76.598834
			50	9.250798	76.591825
			51	9.255251	76.597816
			52	9.267725	76.597818
			53	9.272197	76.598839
			54	9.290470	76.581452
4.	Venmony	11	55	9.242460	76.626495
			56	9.256714	76.617563
			57	9.240483	76.604265
			58	9.238538	76.641717
			59	9.238828	76.641869
			60	9.245146	76.616261
			61	9.241858	76.650582
			62	9.248417	76.651307
			63	9.255999	76.627939
			64	9.265889	76.626697
			65	9.246091	76.638907
5.	Ala	10	66	9.265556	76.610561
			67	9.271974	76.612780
			68	9.281120	76.612229
			69	9.282201	76.621835
			70	9.289328	76.610893
			71	9.293552	76.618850
			72	9.288200	76.604127
			73	9.293736	76.599203
			74	9.299237	76.606334
			75	9.288060	76.621016

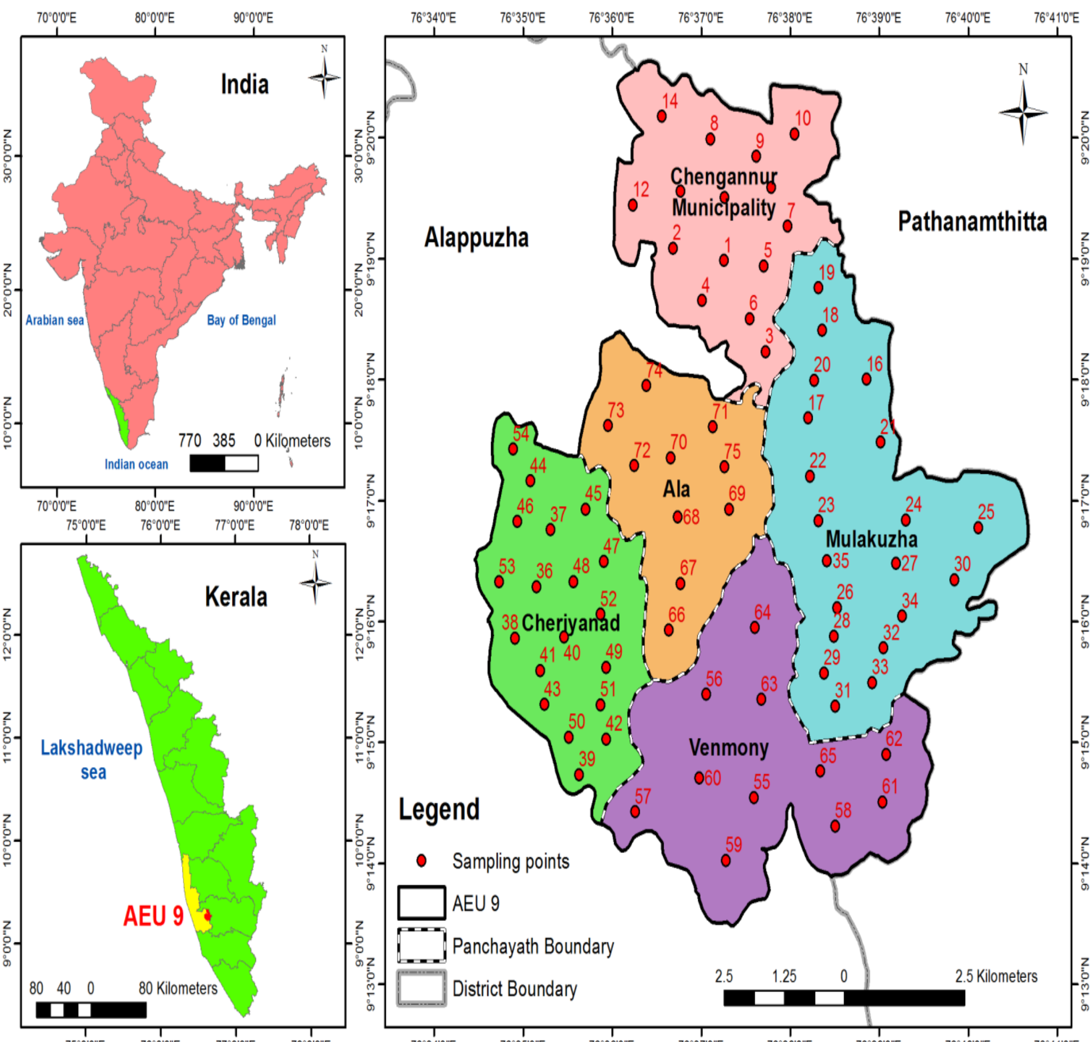


Fig. 1 Location map of study area in AEU 9 of Alappuzha district

3.1.4. Processing of soil samples

The soil samples were shade dried, powdered with wooden pestle and mortar, sieved through a 2mm sieve and stored in labelled plastic containers. A portion of unprocessed soil sample and core samples were stored for the determination of aggregate stability and bulk density respectively.

3.1.5 Weather parameters of the study area

The weather data of the study area from May 2018 to May 2019 and the 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 and minimum temperature, relative humidity, rainfall and number of rainy days are graphically 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.

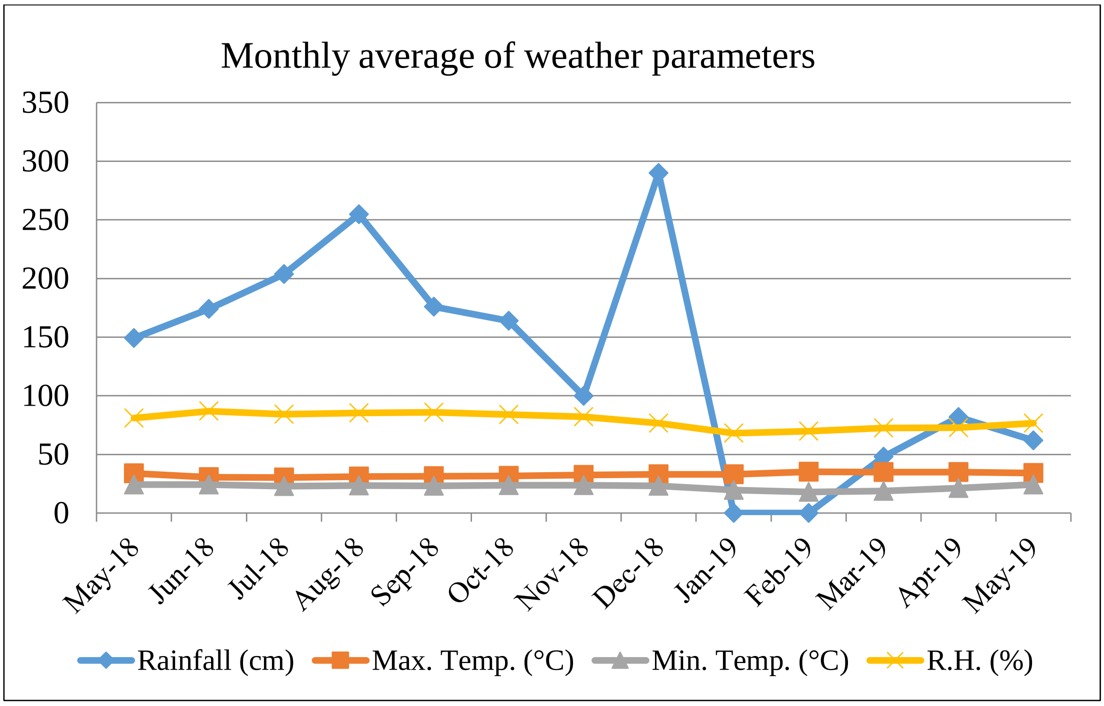


Fig 2. Monthly mean of weather parameters in AEU 9 (May 2018 to May 2019)

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 (cm)	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

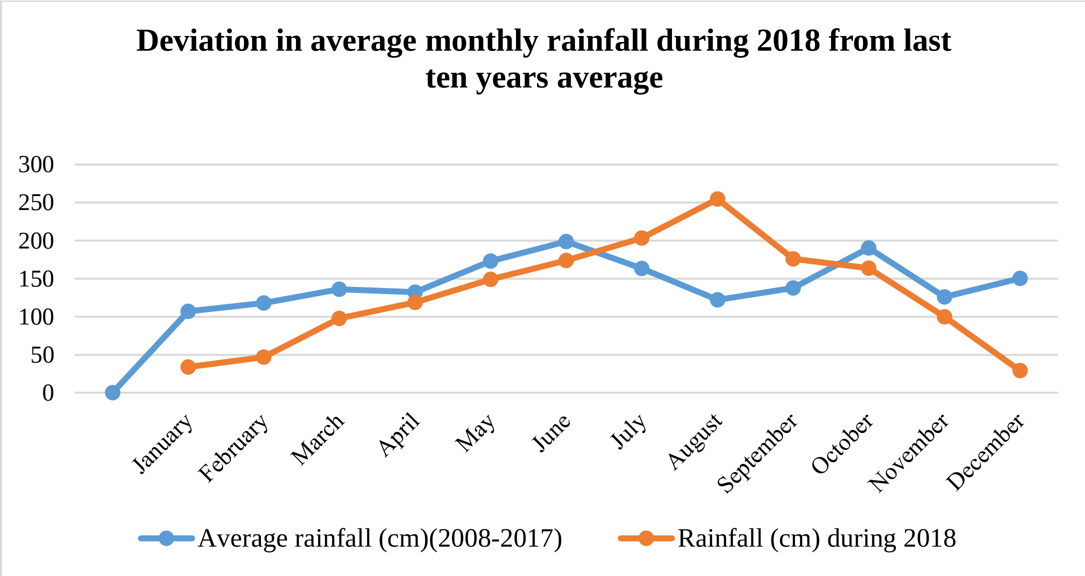


Fig 3. Deviation in average monthly rainfall during 2018 from the average of last ten years

3.2 CHARACTERIZATION OF SOIL

Soil samples collected from flood affected panchayats of AEU 9 were characterized for physical, chemical and biological parameters using standard procedures. The analytical methods followed are given in table 3.

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

Sl. No.	Soil parameters	Method	Reference
1	Bulk density	Undisturbed core sample	Black *et al*. (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	Dakshinamurthy and Gupta (1980)
6	Soil texture	Bouycous hydrometer method	Bouyoucos (1936)
7	pH	pH meter (1:2.5 soil: water ratio)	Jackson (1973)
8	Electrical conductivity	Conductivity meter (1:2.5 soil: water ratio)	Jackson (1973)

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

9	Exchangeable acidity	1N KCl extraction and standard alkali titration	Sarma *et al*. (1987)
10	Organic carbon	Walkley and Black method	Walkley and Black (1934)
11	Available nitrogen	Alkaline permanganate method	Subbiah and Asija (1956)
12	Available phosphorous	Extraction using Bray No.1 solution and spectrophotometry	Bray and Kurtz (1945)
13	Available potassium	Neutral normal ammonium acetate extraction and flame photometry	Jackson (1973)
14	Exchangeable calcium and magnesium	Versanate titration method	Hesse (1971)
15	Available sulphur	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)
16	Available boron	Hot water extraction and spectrophotometry (Azomethane-H reagent method)	Gupta (19)
17	Acid phosphatase activity	Colorimetric estimation of PNP released	Tabatabai and Bremer (1969)
18.	Dehydrogenase activity	Colorimetric estimation of TPF hydrolysed	Casida *et al*. (1977)

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

A minimum data set (MDS) for the assessment of soil quality was set up after carrying out the principal component analysis. It is based on the assumption that the principal components with higher eigen values greater than one, best represent the attributes to be selected. The contribution of each variable to the principal component is represented by weightage or factor loading it received. Only the highly weighted variables (within 10% of the highest observed factor loading) in each principal component were retained. When more than one variable was retained in a principal component, linear correlation between the retained variables was considered to check redundancy. In case, the retained parameters were highly correlated (correlation coefficient r> 0.6) only the variables with highest sum of correlation coefficients were selected for the MDS (Andrews *et al*., 2004).

3.4 FORMULATION OF SOIL QUALITY INDEX

3.4.1 Soil Quality Index (SQI)

The soil quality was evaluated as per the procedure described by Larsen and Pierce (1991). The attributes in the MDS were assigned an appropriate weight. Each attribute was categorized into four classes *viz.* class-I (very good), class-II (good), class-III (poor) and class-IV (very poor) and assigned scores of 4,3,2 and 1 respectively (Kundu *et al.*, 2012; Mukherjee and lal, 2014) with slight modifications based on soil fertility ratings for Kerala soils.

Soil quality index (SQI) was calculated by the equation,

$$SQI = \Sigma\ Wi\ Si$$

Where, Wi is the weight of indicators and Si is the score assigned to the indicator class.

3.4.2 Relative soil quality index

Relative soil quality index (RSQI) was calculated to measure the changes in the soil quality using the equation given by Karlen and Stott (1994)

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

Where SQI was the calculated soil quality index and SQI_m was the theoretical maximum soil quality index. Then each sampling locations in the study area were rated based on the RSQI value as suggested by Kundu *et al.*, (2012).

Table 4. Relative soil quality index ratings

Sl.	RSQI Rating	RQI Value (%)
1	Poor	<50
2	Medium	50 – 70
3	Good	>70

3.5. SOIL NUTRIENT INDEX

In order to evaluate the soil fertility status of the study area, nutrient indices were calculated for soil organic carbon, available nitrogen, phosphorous and potassium in soils using the equation given by Parker *et al*., (1951).

$$NI = \frac{1x\ N_l + 2\ x\ N_m + 3x\ N_h}{N_t}$$

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

Table 5. Nutrient index ratings

Sl. No.	Nutrient index	NI value	Interpretation
1	Low	<1.67	Low fertility status
2	Medium	1.67-2.33	Medium fertility status
3	High	>2.33	High fertility status

3.6. LAND QUALITY INDEX

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

Soil organic carbon stock in the soil was calculated by the formula given 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

SOC 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

3.7. GENERATION OF GIS MAPS

GIS based thematic soil maps were prepared for soil texture, pH, organic carbon, available nitrogen, phosphorus, potassium, calcium, sulphur, soil quality index, land quality index and nutrient indices of organic carbon, nitrogen, phosphorus, potassium using ArcGIS 10.5.1 software following Inverse Distance Weighting method (IDW). Principle underlying IDW interpolation is the First law of Geography formulated by Tobler (1970) which states 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, the 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 below mentioned procedure.

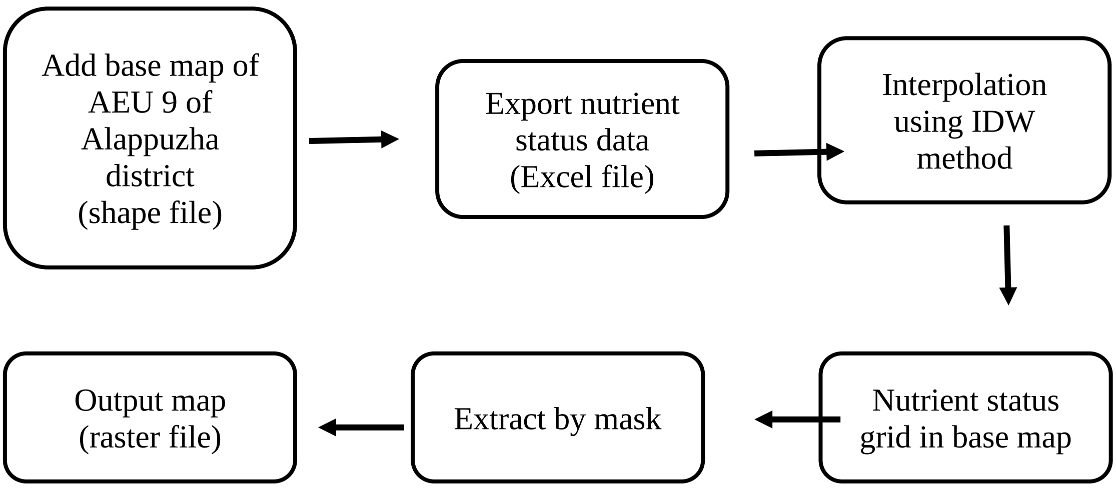


Fig.4. Flow chart of ArcGIS mapping using IDW method.

Various thematic soil maps were prepared for sampling location, soil texture, pH, organic carbon, available nitrogen, phosphorus, potassium, calcium, sulphur, soil quality index, land quality index and nutrient indices of organic carbon, nitrogen, phosphorus and potassium.

3.8. STATISTICAL ANALYSIS

Correlations between physical, chemical and biological properties were done using Pearson's correlation coefficient (Panse and Sukhatme, 1978) using OPSTAT software.

Results

4. RESULTS

The soil quality in AEU 9 of Alappuzha district was evaluated through the present investigation entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Alappuzha district of Kerala and generation of GIS maps". A survey was conducted and georeferenced surface soil samples were collected from the selected panchayaths in AEU 9 of Alappuzha district affected by the flood during August 2018. Soil samples collected were analyzed for physical, chemical and biological characteristics in the laboratory. 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 ALAPPUZHA DISTRICT

The major rivers Pampa and Manimala draining through Chengannur block overflowed and left the area flooded for almost a week. The entire area in AEU 9 was affected by 2018 flood. The panchayats affected were Ala, Cheriyanad, Mulakuzha and Venmony. Chengannur municipality was the area worst affected by the floods. Water level rose to more than 3 m in and around Edanad and the area remained flooded for about a week. On the banks of river Pampa, at Arattukadavu, sediment deposition was found to a height of about 1.5 m. The areas like Ala adjacent to Achenkovil river, the canals were flooded to about 1-1.5 m height.

The details on crops, nutrient management practices and size of holdings are provided in table 7. The devastating flood during August 2018 has caused immense yield loss all over AEU 9. Crops such as banana, nutmeg, tuber crops, paddy and vegetables were the most affected. Nutmeg plants in flood affected areas were severely damaged with yellowing and rotting symptoms after the floods. In banana, Nendran variety was the most affected while Palayamkodan and Njalipoovan thrived the situation. Farmers reported incidence of fungal and bacterial infection immediately after the flood.

Majority (60%) of the area is under coconut based cropping system. More than 70% of farmers are marginal farmers (< 1ha) and others are small farmers (1 -2 ha). Integrated nutrient management practices was practiced by majority of the farmers (70.6%). 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. Locally prepared compost is applied during land preparation and top dressing is done with biogas slurry and liquid organic manures. 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 Alappuzha district

Particulars	No. of farmers	Percentage
Crops		
1. Coconut	45	60.1%
2. Banana	7	9.31%
3.Nutmeg	6	8%
4.Vegetables	7	9.33%
5. Paddy	5	6.60%
6. Others	5	6.60%
Nutrient management		
1. INM	53	70.6%
2. Organic	13	17.3%
3. Conventional	9	12.1%
Size of holdings		
1. <1 ha	54	70.2%
2. >1 ha	21	29.8%

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 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 1.10 and 1.80 Mg m^{-3} with a mean of 1.41 Mg m^{-3}. The lowest and highest mean values were observed for Chengannur municipality (1.33 Mg m^{-3}) and Venmony panchayat (1.60 Mg m^{-3}) respectively (Table 8).

Particle density ranged between 2.10 and 2.60 Mg m^{-3} in the post- flood soils with a mean value of 2.21 Mg m^{-3}. The lowest and highest mean at panchayat level were observed for Chengannur municipality (2.13 Mg m^{-3}) and Mulakuzha panchayat (2.22 Mg m^{-3}) respectively (Table 8).

Porosity ranged from 44.1 to 78.1% with a mean of 65%. The highest and lowest mean were recorded in Venmony panchayat (71.6%) and Chengannur municipality (60.6%) respectively (Table 8).

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

Panchayat/ Muncipality	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Range	Mean ± SD	Range	Mean± SD	Range	Mean ± SD
Chengannur	1.10 - 1.61	1.33 ± 0.12	2.10-2.60	2.13 ± 0.13	44.1 -73.0	60.6 ± 8.32
Mulakuzha	1.10 - 1.62	1.35 ± 0.18	2.10-2.60	2.22 ± 0.22	49.3-78.1	61.9 ± 8.73
Cheriyanad	1.10 - 1.80	1.47 ± 0.21	2.10-2.31	2.14 ± 0.12	52.8- 70.6	65.4 ± 6.75
Venmony	1.20 - 1.71	1.60 ± 0.15	2.10-2.31	2.21 ± 0.14	58.1 -76.9	71.6 ± 5.30
Ala	1.20 - 1.60	1.43 ± 0.14	2.10-2.32	2.17 ± 0.13	60.1-76.8	64.9 ± 6.80
AEU 9	1.10 - 1.80	1.41 ± 0.20	2.10-2.60	2.21 ± 0.17	44.1 -78.1	65.0 ± 9.41

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 sandy loam which was observed in Mulakuzha, Cheriyanad, Venmony and Ala panchayats. Silty clay texture was observed in Chengannur municipality. Sand content varied between 9.91 and 79.9% with highest and lowest mean values in Cheriyanad (67.1%) and Chengannur (26.2%) respectively. Silt content varied between 11.1 and 57.8% and the lowest and highest mean values were obtained in Cheriyanad (22.1%) and Mulakuzha (38.2%) respectively. Clay content in the soils ranged from 5.62 to 80.2%. The highest and lowest mean values were recorded for Chengannur (53.2%) and Venmony (12.2%) respectively.

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

Panchayat/ Muncipality	Sand (%)		Silt (%)		Clay (%)		Textural class
	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	
Chengannur	9.91-50.7	26.2 ± 16.4	11.2-57.8	38.1 ± 15.8	35.5 -78.9	53.2 ± 11.8	Silty clay
Mulakuzha	29.8-79.9	55.6 ± 17.7	23.3-56.7	38.2 ± 8.71	6.62 - 80.2	27.3 ± 28.8	Sandy loam
Cheriyanad	50.7-78.6	67.1 ± 9.51	9.81-46.2	22.1 ± 10.4	5.62 -40.7	16.8 ± 13.2	Sandy loam
Venmony	46.7-78.9	59.2 ± 11.8	11.1-45.8	31.2 ± 9.71	6.42 -40.6	12.2 ± 9.12	Sandy loam
Ala	33.8-72.6	55.9 ± 15.5	11.5-49.7	30.8 ± 14.1	9.82 -41.1	23.3 ± 14.3	Sandy loam
AEU 9	9.91–79.9	53.1 ± 20.2	11.1-57.8	32.3 ± 13.2	5.62 -80.2	27.0 ± 22.7	

4.2.1.3 Depth of sand, silt and clay deposits

Deposition of sediments with varying depth and texture were observed in Chengannur, Mulakuzha, Cheriyanad, Venmony and Ala (Table 10). Maximum deposits were observed in Chengannur with sand and clay deposits up to 10 to 15 cm, followed by Cheriyanad and Venmony 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 Mulakuzha and Ala panchayats.

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

Panchayat/ Muncipality	Depth of deposition	Nature of deposits
Chengannur	10-15cm	Sand, clay
Mulakuzha	< 1cm	Sand, silt
Cheriyanad	5 - 10cm	Sand, silt
Venmony	5 - 10cm	Sand, silt
Ala	< 1cm	Sand, silt

4.2.1.4. Soil moisture content and water holding capacity

The highest mean value for soil moisture content was observed in Cheriyanad (18.5%) followed by Chengannur (18.4 %) and the lowest in Venmony (16.5%). **S**oil moisture content varied between 11.3 and 24.4% in the post-flood area of AEU 9 in Alappuzha district with a mean of 17.9% (Table 11)

The water holding capacity was the highest (55.1%) in Chengannur, followed by Mulakuzha (51.3%) and the lowest value was observed in Venmony (39.3 %). The results showed that the water holding capacity ranged between 32.1 and 74.6% in the post-flood soils of AEU 9 with a mean of 47.7% (Table 11).

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

Panchayat/ Muncipality	Soil moisture content (%)		Water holding capacity (%)	
	Range	Mean	Range	Mean
Chengannur	11.3 - 22.5	18.4 ± 3.56	50.2 - 74.6	55.1 ± 5.82
Mulakuzha	12.2 - 22.2	17.8 ± 3.12	33.8 - 69.8	51.3 ± 10.7
Cheriyanad	12.2 - 23.8	18.5 ± 3.47	22.6 - 59.8	43.5 ± 10.26
Venmony	11.8 - 24.4	16.5 ± 3.44	32.2 - 50.2	39.3 ± 8.48
Ala	13.2 - 21.3	17.9 ± 2.71	32.1 - 57.9	46.8 ± 8.13
AEU 9	11.3 - 24.4	17.9 ± 3.28	32.1 - 74.6	47.7 ± 10.45

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 0.21 and 1.02 mm with a mean of 0.61mm. The highest and lowest mean values of MWD were obtained for Venmony (0.76mm) and Chengannur (0.52 mm) respectively. Percentage of water stable aggregates varied between 37.3 and 70.6% in the post-flood soils of AEU 9 in Alappuzha district with a mean of 50.12%. The highest and lowest mean values were recorded in Chengannur (55.61%) and Venmony (46.34%) respectively,

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

Panchayat/ Muncipality	Mean weight diameter (mm)		Water stable aggregates (%)	
	Range	Mean	Range	Mean
Chengannur	0.31 - 0.82	0.52 ± 0.19	44.4 - 70.4	55.6 ± 10.5
Mulakuzha	0.21 - 1.02	0.62 ± 0.26	37.3 - 70.6	50.8 ± 8.67
Cheriyanad	0.42 - 0.81	0.54 ± 0.14	36.6 - 58.5	48.6 ± 6.62
Venmony	0.32 - 0.93	0.76 ± 0.22	42.1 - 55.2	46.3 ± 6.23
Ala	0.41 - 1.01	0.73 ± 0.23	37.3 - 59.3	48.2 ± 5.93
AEU 9	0.21 - 1.02	0.61 ± 0.21	37.3 - 70.6	50.1 ± 8.39

4.2.2 Chemical attributes

The soil samples were analyzed in the laboratory for chemical parameters *viz.* pH, electrical conductivity, exchangeable acidity, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and boron and the results obtained are given below.

4.2.2.1 pH, exchangeable acidity 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 4.10 and 6.90 with a mean of 5.02. The lowest and highest mean value of pH was observed in Cheriyanad (4.84) and Chengannur (5.42) respectively.

The exchangeable acidity of post-flood soils of AEU 9 in Alappuzha district was in the range of 1.00 and 3.00 c mol g^{-1} with a mean of 1.80 c mol g^{-1}. The highest mean value was obtained in Ala (2.54 c mol g^{-1}), followed by Cheriyanad (1.97 c mol g^{-1}) and the lowest in Mulakuzha (1.62 c mol g^{-1}).

EC ranged between 0.10 and 0.40 dS m^{-1} in the post-flood soils of AEU 9 in Alappuzha district with a mean of 0.20 dS m^{-1}. The lowest mean value of 0.10 dS m^{-1} was obtained in Chenganuur followed by Ala (0.11 dS m^{-1}), Cheriyanad (0.19 dS m^{-1}), Mulakuzha (0.20 dS m^{-1}) and Venmony (0.20 dS m^{-1}).

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

Panchayat/ Muncipality	Soil pH		Exchangeable Acidity (c mol g^{-1})		Electrical Conductivity (dSm^{-1})	
	Range	Mean	Range	Mean	Range	Mean
Chengannur	4.51-6.90	5.42 ± 0.83	1.33-2.33	1.82 ± 0.44	0.10-0.40	0.10 ±0.10
Mulakuzha	4.22-5.60	4.93 ± 0.52	1.00-2.66	1.62 ± 0.51	0.10-0.40	0.20± 0.10
Cheriyanad	4.10-6.10	4.84 ± 0.58	1.33-2.66	1.97 ± 0.42	0.10-0.60	0.19±0.13
Venmony	4.41-6.62	5.22 ± 0.73	1.00-2.33	1.74 ± 0.38	0.10-0.20	0.20± 0.10
Ala	4.32-5.65	5.13 ± 0.42	2.00-3.00	2.54 ± 0.32	0.10	0.11±0.10
AEU 9	4.10-6.90	5.02 ± 0.61	1.00-3.00	1.80 ± 0.55	0.10-0.40	0.20±0.10

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 0.51 to 2.62 % with a mean value of 1.42%. It was the highest in Chengannur (2.41%) followed by Mulakuzha (1.61%) and the lowest soil organic carbon was observed in Ala (0.81%).

4.2.2.3 Available nitrogen, phosphorous and potassium

The results of available nitrogen in post flood soils of AEU 9 in Alappuzha district revealed that the values varied from 100 to 627 kg ha^{-1} with a mean of 197 kg ha^{-1} (Table 14). The highest available nitrogen status of 233 kg ha^{-1}was recorded in Mulakuzha followed by Ala (219 kg ha^{-1}) and the lowest in Chengannur (156 kg ha^{-1}).

Available phosphorus content in study area varied between 8.32 and 47.8 kgha^{-1} with a mean of 14.8 kgha^{-1} (Table 14). The highest available phosphorus of 19.2 kgha^{-1} was obtained in Mulakuzha which was followed by Chengannur (16.2 kg ha^{-1}). The lowest phosphorus availability of 10.2 kg ha^{-1} was observed in Venmony.

Available K in the post-flood area of AEU 9 in Alappuzha district varied between 100 and 492 kg ha^{-1} with a mean of 252 kgha^{-1} (Table 14). The availability of potassium in soil was found to be highest in Mulakuzha (299 kgha^{-1}), followed by Cheriyanad (280 kgha^{-1}). The lowest value was observed in Chengannur (177 kgha^{-1}).

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

Panchayat/ Muncipality	Organic Carbon (%)		Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available potassium (kg ha^{-1})	
	Range	Mean ±SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ±SD
Chengannur	1.61-3.92	2.41 ± 0.62	100-263	156 ± 44.4	9.32-44.6	16.2 ± 9.22	100 – 246	177 ± 40.6
Mulakuzha	1.12-2.42	1.61 ± 0.42	100-627	233 ± 116	8.32-47.8	19.2 ± 11.9	112 – 492	299 ± 115
Cheriyanad	0.51-2.62	0.95 ± 0.47	112-526	183 ± 89.7	9.21-29.8	13.1 ± 6.31	123 – 460	280 ± 105
Venmony	0.52-1.23	0.82 ± 0.18	138-238	189 ± 31.9	9.13-14.7	10.2 ± 1.72	112 – 380	219 ± 82
Ala	0.51-1.33	0.81 ± 0.32	163-363	219 ± 69.3	9.02-28.0	12.3 ± 5.85	123 – 436	254 ± 101
AEU 9	0.51-2.62	1.42 ± 0.73	100-627	197 ± 85.8	8.32-47.8	14.8 ± 8.78	100 – 492	252 ± 103

4.2.2.4. Available calcium, magnesium and sulphur

The results with respect to availability of secondary nutrients *viz.* calcium, magnesium and sulphur are given in table 15. Available Ca ranged between 110 and 478 mg kg^{-1}in the post-flood area with a mean of 239 mg kg^{-1}. The highest available Ca was recorded in Chengannur (327 mg kg^{-1}) followed by Mulakuzha (259 mg kg^{-1}) and the lowest in Cheriyanad (189 mg kg^{-1}).

Available Mg in soil varied between 46.9 and 105 mg kg^{-1} and the mean value was 76.4 mg kg^{-1}. It was the highest in Venmony (129 mg kg^{-1}) followed by Cheriyanad (71 mg kg^{-1}) and the lowest in Ala (59.7 mg kg^{-1}).

Available S varied between 3.02 and 27.5 mg kg^{-1} with mean value of 10.82 mg kg^{-1}. The highest and lowest mean value for available Sulphur in soil were observed in Venmony (17.91 mg kg^{-1}) and Chengannur (5.71mg kg^{-1}) respectively.

4.2.2.5. Available boron

The available B in in the post flood soil of AEU 9 in Alappuzha district varied between 0.01 mg$kg^{-1}$and 0.41 mg kg^{-1} with mean of 0.10 mg kg^{-1}. (Table 15). Chengannur recorded the highest available boron of 0.31 mg kg^{-1} followed by Venmony (0.20 mg kg^{-1}). Cheriyanad recorded the lowest available boron of 0.11 mgkg^{-1} .

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

Panchayat/ Muncipality	Available calcium (mg kg^{-1})		Available magnesium (mg kg^{-1})		Available sulphur (mg kg^{-1})		Available boron (mg kg^{-1})	
	Range	Mean± SD	Range	Mean ± SD	Range	Mean ±SD	Range	Mean ± SD
Chengannur	110 - 478	327 ± 130	50.4 -109	64.5 ± 18.7	3.02 -10.0	5.71 ± 1.82	0.01 - 0.61	0.31 ± 0.22
Mulakuzha	110 - 378	259 ± 95.7	50.4 - 99.4	69.4 ± 15.7	5.52-19.5	11.4 ± 3.94	0.01 - 0.21	0.12 ± 0.07
Cheriyanad	110 - 321	189 ± 73.2	50.3 - 103	71.0 ± 22.3	4.51-23.5	10.5 ± 6.64	0.01 - 0.51	0.11 ± 0.10
Venmony	123 - 374	189 ± 77.8	81.0 - 105	129 ± 49.9	5.52-25.5	17.9 ± 8.37	0.12 - 0.53	0.20 ± 0.10
. Ala	112 - 377	221 ± 99.0	46.9 - 92.4	59.7 ± 15.5	5.02-27.5	10.2 ± 7.64	0.01 - 0.23	0.13 ± 0.10
AEU 9	110 - 478	239 ± 107	46.9- 105	76.4 ± 33.5	3.02-27.5	10.8 ± 6.65	0.01 - 0.41	0.10 ± 0.14

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 16 revealed that the acid phosphatase activity ranged between 16 and 37.8 µg PNP produced g^{-1} h^{-1} with a mean of 25.62 µg PNP produced g^{-1} h^{-1}. The highest and lowest activity was observed in Chengannur (29.62 µg PNP produced $g^{-1}h^{-1}$) and Ala (19.51µg PNP produced g^{-1} h^{-1}) respectively.

4.2.3.2 Dehydrogenase activity

Dehydrogenase activity varied between 13.1 and 27.3 µg TPF hydrolysed g^{-1}soil 24 hr^{-1}) with a mean value of 25.4 µg TPF hydrolysed g^{-1} soil 24 hr^{-1} (Table 16). The highest mean value was observed in Mulakuzha (26.3 µg TPF hydrolysed g^{-1} soil 24 hr^{-1}) and lowest in Chengannur (25.2 µg TPF hydrolysed g^{-1} soil 24 hr^{-1})

Table 16. Acid phosphatase and dehydrogenase activity in the post-flood soils of AEU 9 in Alappuzha district

Panchayat/ Muncipality	Acid phosphatase (µgm PNP produced g^{-1} h^{-1})		Dehydrogenase (µg TPF hydrolysed g^{-1}soil 24 hr^{-1})	
	Range	Mean ± SD	Range	Mean ± SD
Chengannur	17.7 - 36.7	29.62 ± 8.02	17.0 - 25.7	25.2 ± 3.12
Mulakuzha	21.1 - 34.5	25.41 ± 4.83	17.9 - 26.9	26.3 ± 3.52
Cheriyanad	19.0 - 33.8	25.42 ± 4.31	13.1 - 25.5	25.3 ± 4.02
Venmony	16.0 - 29.5	26.01 ± 5.62	13.1 – 26.8	26.2 ± 4.62
Ala	18.4 - 37.8	19.51 ± 5.82	17.9 - 27.3	26.2 ± 3.21
AEU 9	16.0 - 37.8	25.62 ± 6.19	- 27.3	25.4 ± 3.68

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. All the soil parameters analyzed were used in PCA, which 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, organic carbon, available primary and secondary nutrients, available B, 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 22.1%, 32.8%, 41.1% ,48.4%,55.2%,61.5% and 67.3% variance respectively (Table 17).

The factor loadings of variables under a particular PC denote the contribution of that variable to the PC. Only highly weighted variables within 10% 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 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 17. Result of principal component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen value	3.987	1.909	1.5	1.309	1.226	1.14	1.048
% variance	22.1	10.6	8.3	7.3	6.8	6.3	5.8
Cumulative variance	22.1	32.8	41.1	48.4	55.2	61.5	67.3
Eigen vectors							
Particle density (Mgm^{-3})	-0.084	-0.136	0.117	0.149	0.211	0.202	0.117
Bulk density (Mgm^{-3})	0.084	-0.106	0.183	0.179	**0.522***	**0.444***	-0.310
Soil moisture content (%)	-0.106	-0.143	0.458	-0.378	-0.204	0.018	-0.028
Water holding capacity (%)	-0.195	-0.338	0.438	-0.129	0.004	-0.103	0.113
Mean weight diameter (mm)	-0.286	-0.209	-0.062	-0.225	-0.138	-0.026	0.022
Water stable aggregates (%)	0.158	0.295	-0.078	-0.179	0.322	0.371	-0.024
Sand (%)	0.283	-0.099	0.036	0.321	-0.072	-0.08	0.085
Silt (%)	0.178	0.193	0.291	0.249	0.124	-0.205	0.217
Clay (%)	**-0.404***	-0.341	-0.201	0.056	0.26	0.052	-0.184
pH	0.2875	0.09	-0.096	-0.106	-0.031	0.236	0.161
EC (dSm^{-1})	-0.041	-0.093	-0.144	-0.306	-0.171	-0.145	**-0.573***
OC%	0.132	-0.057	-0.069	-0.245	0.161	0.113	0.232
N ($kgha^{-1}$)	-0.131	-0.212	**0.513***	0.224	-0.189	0.374	-0.196
P ($kgha^{-1}$)	0.242	**-0.364***	0.101	-0.112	0.174	-0.074	0.071
K ($kgha^{-1}$)	-0.22	**0.398***	0.092	0.031	0.03	-0.371	0.444
Ca ($mgkg^{-1}$)	-0.195	-0.182	0.179	**-0.518***	-0.056	-0.122	-0.197
Mg ($mgkg^{-1}$)	0.148	0.295	0.197	-0.074	0.106	0.352	0.277
S ($mgkg^{-1}$)	-0.042	-0.047	0.067	0.046	**0.497***	0.034	0.045
B ($mgkg^{-1}$)	0.034	0.046	0.0876	0.062	--0.067	0.035	0.034
Ex. acidity	0.132	-0.324	-0.069	-0.245	0.161	-0.113	-0.232
Acid phosphatase	-0.131	-0.318	-0.144	0.224	0.189	0.374	0.196
Dehydrogenase	0.242	-0.057	0.101	-0.438	0.174	-0.074	0.071

*Parameters used in MDS

In the first principal component, clay had the highest factor loading and hence was selected. Available P and K were the highly weighted variable in the second PC which were found non-correlated and hence retained.

Available N was selected from PC 3 and available Ca was retained from the fourth principal component. In the fifth PC, bulk density and available S were retained. In the sixth PC, again bulk density was retained and in the seventh principal component electrical conductivity was retained. The minimum data set selected thus consisted of eight parameters (Table 18).

Table 18. Minimum Data Set (MDS) selected from PCA

PC1	PC2	PC3	PC4	PC5	PC6	PC7
Clay per cent	Available P	Available N	Available Ca	Bulk density	Bulk density	Electrical conductivity
	Available K			Available S		

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 (Lansen and Pierce, 1991). Scoring was done following the method suggested by Kundu *et al*. (2012) and Lal and Mukherjee (2014) with slight modifications based on soil fertility ratings for Kerala soils. Available N and P were assigned with the highest weightage of 20 each followed by bulk density, texture, electrical conductivity, available K, Ca and S with weightage of 10 each and were categorized into four classes with scores ranging from 4 to 1 (Table 19).

Table 19. 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 ($Mg\ m^{-3}$)	10	1.3 – 1.4	1.2 – 1.3 or 1.4 – 1.5	1.1 – 1.2 or 1.5 – 1.6	< 1.1/ > 1.6
Texture (clay %)	10	Loam	Clay loam/ Sandy loam	Sand/Clay	Grit
EC ($dS\ m^{-1}$)	10	<2	2-4	4-8	8-16
Available N ($kg\ ha^{-1}$)	20	>560	560-420	420-280	<280
Available P ($kg\ ha^{-1}$)	20	>25	15 - 25	15 – 10	<10
Available K ($kg\ ha^{-1}$)	10	>280	280-200	200-120	<120
Available Ca ($mg\ kg^{-1}$)	10	>300	300 - 250	250 – 150	<150
Available S ($mg\ kg^{-1}$)	10	>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 120 to 250 with a mean value of 174 (table 20). The relative soil quality index (RSQI) ranged from 32.5 to 62.5 percent with a mean of 43.6 percent. The highest mean value of relative soil quality index was observed in Mulakuzha (48.8 %), followed by Cheriyanad (45.7%) and Chengannur (44.8%) and the lowest in Venmony (37.0%).

Table 20. SQI and RSQI of flood affected soils of AEU 9 in Alappuzha district

Panchayat/ Municipality	SQI		RSQI (%)	
	Range	Mean	Range	Mean
Chengannur	130 - 225	180 ± 28.6	40.0 - 55.0	44.8 ± 6.79
Mulakuzha	150 - 250	195 ± 35.7	36.3 - 62.5	48.8 ± 8.81
Cheriyanad	135 - 220	168 ± 26.3	33.8 - 55.0	45.7 ± 6.60
Venmony	130 - 170	149 ± 17.2	32.5 - 42.5	37.0 ± 4.20
Ala	120 - 185	165 ± 25.1	35.0 - 48.8	41.3 ± 6.29
AEU 9	120 - 250	174.± 31.5	32.5 - 62.5	43.6 ± 7.87

4.5 NUTRIENT INDEX

Nutrient indices were calculated for organic carbon, available nitrogen, phosphorous and potassium and presented in table 21. Nutrient indices for organic carbon and nitrogen were medium and low respectively for all the panchayats. Nutrient indices for available phosphorous was low for Venmony (1.2) and medium for Chengannur (1.6), Mulakuzha (1.9), Cheriyanad (1.5) and Ala (1.4). Nutrient indices for available potassium were high for Mulakuzha (2.4), Cheriyanad (2.5) and medium for Chengannur (1.9), Venmony (2.2) and Ala (2.3).

Table 21. Nutrient index of post-flood soils of AEU 9 of Alappuzha district

Panchayat/ Municipality	Nutrient Index (NI)							
	Organic carbon		Available N		Available P		Available K	
	NI	Rating	NI	Rating	NI	Rating	NI	Rating
Chengannur	2.1	Medium	1	Low	1.6	Medium	1.9	Medium
Mulakuzha	2.0	Medium	1.3	Low	1.9	Medium	2.4	High
Cheriyanad	1.8	Medium	1.1	Low	1.5	Medium	2.5	High
Venmony	1.8	Medium	1	Low	1.2	Low	2.2	Medium
Ala	1.7	Medium	1.2	Low	1.4	Medium	2.3	Medium

4.6. LAND QUALITY INDEX

Soil organic carbon stock ranged between 1.02 and 7.02 kgm^{-2} in the study area with a mean of 2.90 kgm^{-2} .The lowest and highest values were observed in Venmony (1.86kgm^{-2}) and Chengannur (6.76 kgm^{-2}) respectively. LQI was found to be medium in Chengannur, low in Mulakuzha and very low in rest of the panchayats Cheriyanad, Venmony and Ala

Table 22. Soil Organic Carbon stock and Land Quality Index in the flood affected soils of AEU 9 in Alappuzha district

Panchayat/ Municipality	SOC stock (Mg ha $^{-1}$)	SOC Stock (Kg m^{-2})		LQI
		Range	Mean ± SD	
Chengannur	23.9 - 70.2	2.39 - 7.02	6.76 ± 1.14	Medium
Mulakuzha	20.6 - 47.9	2.06 - 4.79	3.07 ± 0.76	Low
Cheriyanad	10.2 - 53.0	1.02 - 5.30	2.11 ± 1.01	Very low
Venmony	12.9 - 28.8	1.29 - 2.88	1.86 ± 0.42	Very low
Ala	14.0 - 39.2	1.40 - 3.92	2.43 ± 0.78	Very low
AEU 9	10.2 - 70.2	1.02 - 7.02	2.90 ± 1.34	

4.7 GENERATION OF GIS MAPS

Spatial variability of soil pH, texture, organic carbon, available N, P, K, Ca, Mg and B in flood affected area of AEU 9 were mapped. Soil quality index, land quality index and nutrient indices of organic carbon and available primary nutrients 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 23).

Organic carbon showed a significant negative correlation with bulk density (-0.246**), porosity (-0.235**), sand (-0.559**) and a positive correlation with water stable aggregates (0.243*), silt (0.406**) and clay (0.502**). Bulk density showed negative correlation with water holding capacity (-0.416**), clay (-0.369**), sand (-0.229*). Porosity showed negative correlation with water holding capacity (-0.330*), silt (-0.362**) and clay (-0.480**). A positive correlation was observed between water holding capacity and clay (0.702**) but was negatively correlated with sand (-0.423**) and silt (-0.005**). Sand negatively correlated with silt (-0.249**) and clay (-0.705**). A positive correlation was observed between MWD and water stable aggregates (0.242**) and water stable aggregates and clay (0.319**)

.4.8.2 Correlation between physical and chemical parameters

Correlation data presented in table 24 revealed that the soil pH had significant positive correlation with maximum water holding capacity (0.250**), porosity (0.838**), and clay (0.753**) but significant negative correlation with bulk density (-0.623**), particle density (-0.346**), soil moisture content (-0.372**) and mean weight diameter (-0.544**). Electrical conductivity showed positive correlation with particle density (0.593**), moisture content (0.503**) and percentage of silt (0.235*) and negatively correlated with maximum water holding capacity (-0.293*), porosity (-0.426**), and percentage of clay (-0.431**).

Organic carbon was positively correlated with particle density (0.503**) and moisture content (0.295*) and negatively correlated with maximum water holding (-0.281*), porosity (-0.525**) and percentage of clay (-0.543**). Nitrogen had positive correlation with maximum water holding capacity (0.356**) and percentage of clay (0.302**) and showed negative correlation with particle density (-0.326**). A positive correlation was observed between available P and particle density (0.298**). Potassium was positively correlated with mean weight diameter (0.292*). Calcium showed positive correlation with maximum water holding capacity (0.383**), porosity (0.536**) and percentage of clay (0.773**) and negative correlation with bulk density (-0.413**), particle density (-0.490**), soil moisture content (-0.254*) and mean weight diameter (-0.367**). Magnesium showed positive correlation with porosity (0.310**), percentage of clay (0.318**) and negative correlation with bulk density (-0.567**) and mean weight diameter (-0.560**). Sulphur showed positive correlation with particle density (0.455**), soil moisture content (0.249*) and percentage of silt (0.235*) but negative correlation with maximum water holding capacity (-0.238*), Porosity (-0.307**), mean weight diameter (-0.249*) and percentage of clay (-0.357**).

4.8.3 Correlation between chemical and biological parameters

Organic carbon was negatively corelated with magnesium (-0.250*) and Sulphur (-0.377**) whereas it positively correlated with boron (0.288*) and calcium (0.313**). Potassium is positively correlated with Sulphur (0.282*) and negatively correlated with boron (-0.230*). Magnesium is positively correlated with Sulphur (0.343**) and exchangeable acidity (0.325**). Boron is negatively correlated with dehydrogenase (- 0.246*) (Table 25)

Table 23. Correlation between organic carbon and physical parameters

	Organic carbon	Particle density	Bulk density	Porosity	SMC	WHC	Mean weight diameter	Water stable aggregates	Sand	Silt	Clay
Organic carbon	1.000										
Particle density	0.022	1.000									
Bulk density	-0.246**	-0.076	1.000								
Porosity	-0.235**	0.193	0.295	1.000							
SMC	0.114*	-0.031	-0.166	-0.095	1.000						
WHC	0.418	0.044	-0.416**	-0.330**	-0.041	1.000					
Mean weight diameter	-0.187	-0.199	0.052	0.047	-0.041	-0.185	1.000				
Water stable aggregates	0.243*	-0.023	-0.201	-0.169	-0.124	0.293**	0.242**	1.000			
Sand	-0.559**	-0.213	-0.229*	0.367**	0.090	-0.423**	0.157	-0.136	1.000		
Silt	0.406*	0.134	-0.100	-0.362**	0.054	-0.005**	-0.061	-0.136	-0.249**	1.000	
Clay	0.502**	0.014	-0.369**	-0.480**	-0.065	0.702**	-0.319**	0.319**	-0.705**	0.103	1.000

*

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

Table 24. Correlation between physical and chemical parameters

	Bulk density	Particle density	MWHC	Moisture content	Porosity	MWD	WSA	silt	clay	sand
pH	-0.623**	-0.346**	0.250**	-0.372**	0.838**	-0.544**	0.201	0.039	0.753**	0.023
EC	-0.086	0.593**	-0.293*	0.503**	-0.426**	0.000	0.022	0.235*	-0.431**	0.421
Ex. acidity	0.011	0.178	-0.099	-0.059	0.122	0.155	0.121	0.079	-0.942	0.023
OC	0.263*	0.503**	-0.281*	0.295*	-0.525**	0.203	0.022	0.070	-0.543**	0.031
N	0.189	-0.326**	0.356**	-0.159	0.199	0.079	0.063	-0.105	0.302**	0.121
P	-0.019	0.298**	-0.129	0.161	-0.153	0.094	0.021	-0.017	-0.151	0.131
K	0.169	-0.071	-0.056	0.099	-0.051	0.292*	0.034	-0.043	-0.001	0.123
Ca	-0.413**	-0.490**	0.383**	-0.254*	0.536**	-0.367**	0.021	0.003	0.773**	0.110
.1Mg	-0.567**	0.035	0.029	-0.054	0.310**	-0.560**	0.026	0.193	0.318**	0.012
S	-0.137	0.455**	-0.238*	0.249*	-0.307**	-0.249*	0.136	0.235*	-0.357**	0.321
B	0.233	0.234	0.446	0.723	0.456	0.634	0.123	0.623	0.234	0.110

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

Table 25. Correlation between chemical and biological parameters

	pH	EC	OC	N	P	K	Ca	Mg	S	B	Ex. acidity	Acid phosphatase	Dehydrogenase
pH	1.000												
EC	-0.176	1.000											
OC	-0.173	0.032	1.000										
N	0.145	0.012	0.058	1.000									
P	-0.001	0.090	0.218	-0.028	1.000								
K	-0.197	0.158	-0.183	-0.015	0.183	1.0000							
Ca	-0.069	0.032	0.313**	0.034	0.216	-0.163	1.000						
Mg	-0.067	-0.106	-0.250*	0.0145	-0.214	-0.178	-0.189	1.000					
S	-0.003	0.167	-0.377**	0.034	-0.017	0.282*	-0.104	0.343**	1.000				
B	-0.157	0.134	0.288*	0.0564	-0.074	-0.230*	0.238*	-0.011	-0.052	1.000			
Exchangeable acidity	-0.196	0.143	0.123	0.034	-0.071	0.031	-0.055	0.325**	0.093	0.023	1.000		
Acid phosphatase	0.017	0.169	-0.003	-0.196	-0.196	0.169	0.021	-0.218	0.095	-0.031	-0.152	1.000	
Dehydrogenase	-0.151	-0.054	-0.173	0.0234	0.004	0.105	-0.294	-0.077	-0.049	-0.246*	-0.012	-0.013	1.000

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

Discussion

5. DISCUSSION

A study entitled "Assessment of soil quality in the post-flood scenario of AEU 9 in Alappuzha district of Kerala" was undertaken during 2018-20 to study the influence of flood on soil characteristics and quality. The results pertaining to characterisation of soil samples, formulation of soil quality index, land quality index and nutrient index, and generation of GIS maps are discussed in this chapter.

5.1 CHARACTERISATION OF SOIL SAMPLES

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

5.1.1 Physical attributes

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

5.1.1.1 Bulk density

Bulk density is a dynamic property of soil that varies with soil structure, differences in hydrology, cultivation practices and organic addition (Morales – Olmedo *et al.,* 2015) and is highly influenced by the organic matter content, texture, constituent minerals and porosity (Chaudhari *et al.,* 2013).

The bulk density of soil varied between 1.10 and 1.80 Mg m^{-3} with a mean value of 1.41 Mg m^{-3}. The frequency distribution of bulk density in the study area depicted in Fig. 4 revealed that the bulk density of 50.7% of soils lies in the range of 1.4 -1.6 Mg m^{-3}, 24.6% in 1.2 –1.4 Mg m^{-3} and 20% in >1.6 Mgm^{-3} range. Low bulk density (1.33 Mg m^{-3}) was observed in soils of Chengannur where sediment deposit of clay was noticed resulting in higher organic carbon content (2.41%) and clay content (53.2%), while high bulk density was observed in soils with more sand content. Low bulk density might be due to the influence of organic matter content which improved the aggregation of soil particles. These results are in accordance with the findings of Njoku and Okoro (2015) who observed a significant reduction in bulk density after flood as a result of sediment and organic matter accumulation. There exist a significant negative correlation of clay content and organic carbon content with bulk density, whereas a positive correlation was observed between bulk density and sand content. Similar results were obtained by Prevost (2004), Federer *et al.*, (1993), Sakin *et al.*, (2012) and Mestdagh *et al.*, (2006).

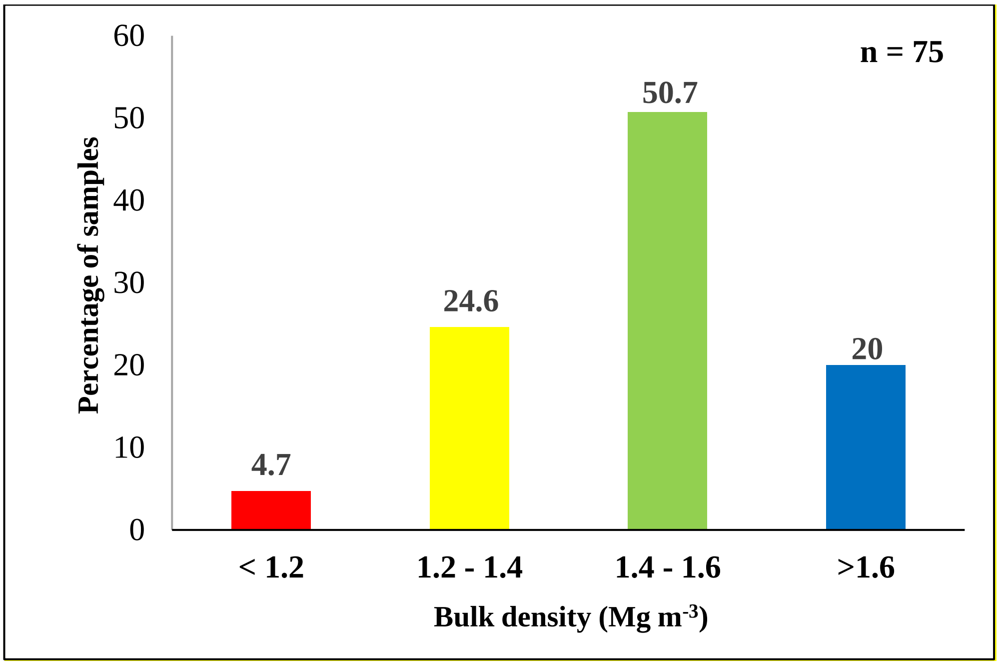


Fig 5. Frequency distribution of bulk density in the post-flood soils of AEU 9 in Alappuzha district

5.1.1.2 Particle density

Particle density of soil varied between 2.10 and 2.60 Mg m^{-3} with a mean value of 2.21 Mg m^{-3} in AEU 9. Lowest values were observed in Chengannur (2.13 Mg m^{-3}) where high contents of silt, clay and organic carbon were noticed which is similar to 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 reported a significant negative correlation between particle density and soil organic matter. Particle density of 57.3 percent of the soils were < 2.2 Mg m^{-3}. 33.4 percent between 2.2-2.4 Mg m^{-3} and 9.33 percent between 2.4-2.6 Mg m^{-3} (Fig. 5). The particle density of a typical mineral soil ranges between 2.65 and 2.75 Mg m^{-3} and in the present study the particle density is much lower than this average value. If soil organic matter is high the particle density even falls below 2.5. These results corroborate well with the relatively high organic matter content (Table 14).

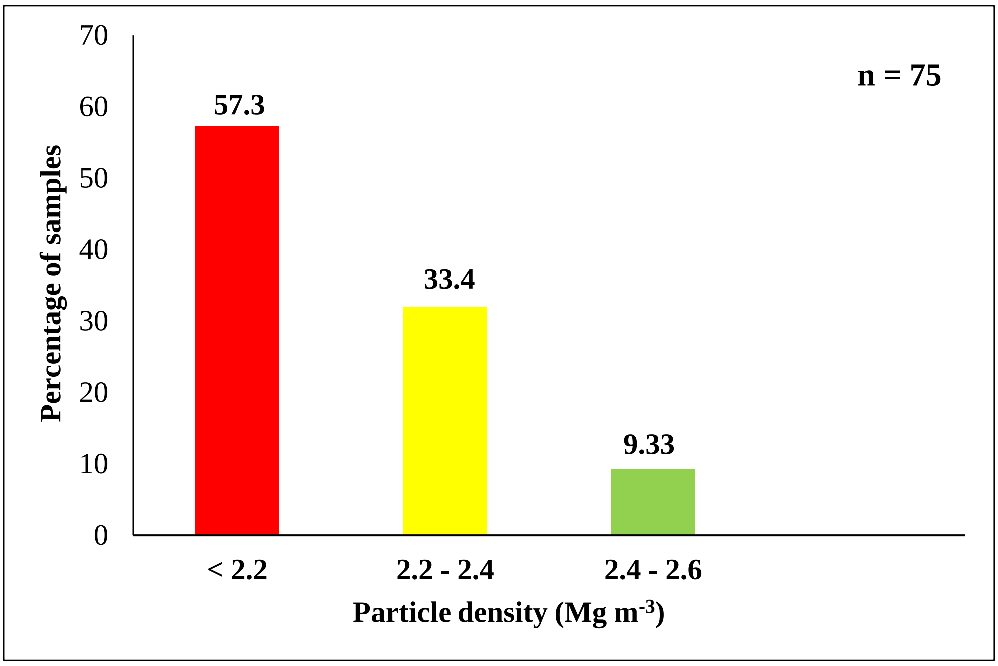


Fig 6. Frequency distribution of particle density in the post-flood soils of AEU 9 in Alappuzha district

5.1.1.3 Porosity

Pore space is essential for the movement of air, water, nutrients and biota within the soil. Porosity varied from 44.1 to 78.1 percent in the study area with a mean value of 65.0%. The high organic carbon content (1.42%) observed in these soils might have favoured soil aggregation and enhancing soil porosity. This is quite evident from the 50-70% porosity recorded in 66.7 percent of soils and >70% porosity in 28 percent soils in the study area (Fig.6). Porosity is significantly and positively correlated with sand and negatively correlated with silt, clay and WHC. This agrees with the findings of Fahmi *et al., (*2014). Njoku and Okoro (2015) also opined that the porosity of soil increases due to the accumulation of sediment materials like debris and sand after the flood.

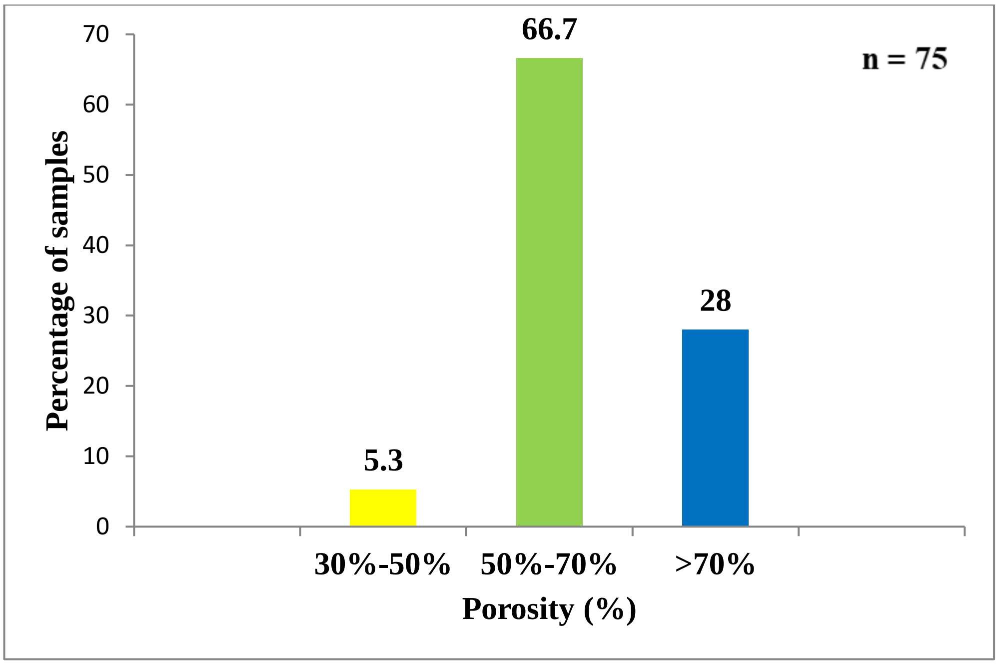


Fig 7. Frequency distribution of porosity in the post-flood soils of AEU 9 in Alappuzha district

5.1.1.4 Soil texture

The proportion of sand, silt and clay indicates the physical nature of soil. Sand, silt and clay content exhibited wide variations in the soils of AEU 9. Clay content varied between 5.62 and 80.20 percent, silt between 11.10 and 57.80 percent and sand between 9.91 and 79.90 percent. Sandy loam was the predominant textural class observed in 58.6% of soils in AEU 9 of Alappuzha district (Fig 7), followed by silty clay and sandy clay in 13.3% of soils.

Silty clay texture was observed in Chengannur where sediments deposits of sand and clay were noticed. Sandy loam texture was observed in all the other panchayats where sediment deposits of sand and silt were noticed. In post-flood soils a slight shift from sandy clay to sandy 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 8.

5.1.1.5 Depth of sand/silt/clay deposition

Sediment deposition of clay, silt or sand were found in the flood affected area of AEU 9 on the banks of river Pamba and Manimala 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. At Araattukadavu in Chengannur municipality sediment deposition was found at a height of about 1.5 m. Sand and clay deposits of 10-15cm thickness were observed in Chengannur whereas sand and silt deposits of 5-10cm were observed in Cheriyanad and Venmony. Sediment deposits were found to be < 1cm in Mulakuzha and Ala. 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.

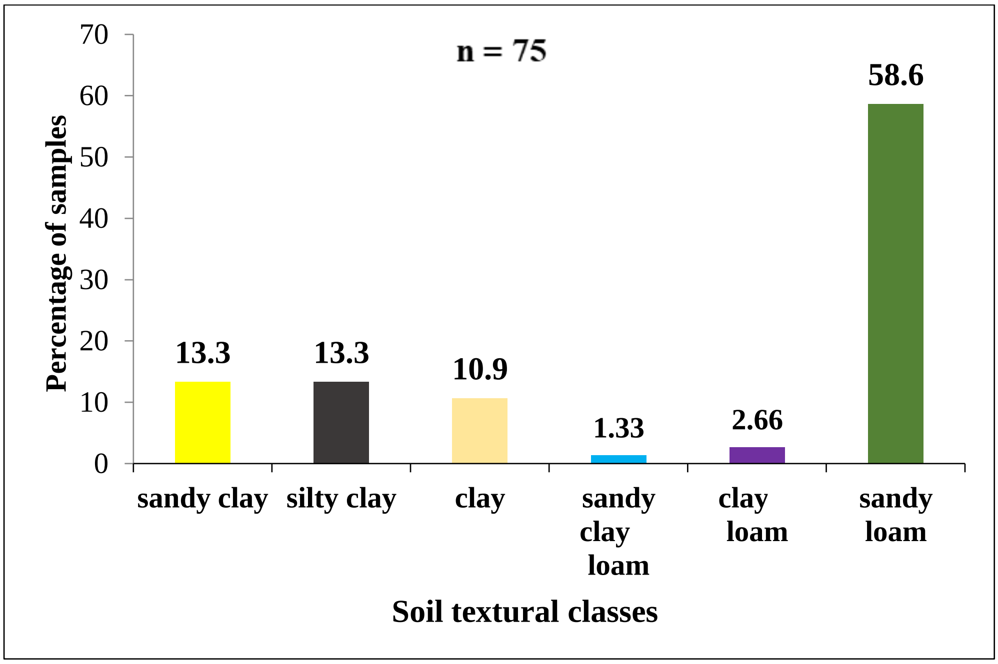


Fig 8. Frequency distribution of soil textural classes in the post- flood soils of AEU 9 in Alappuzha district

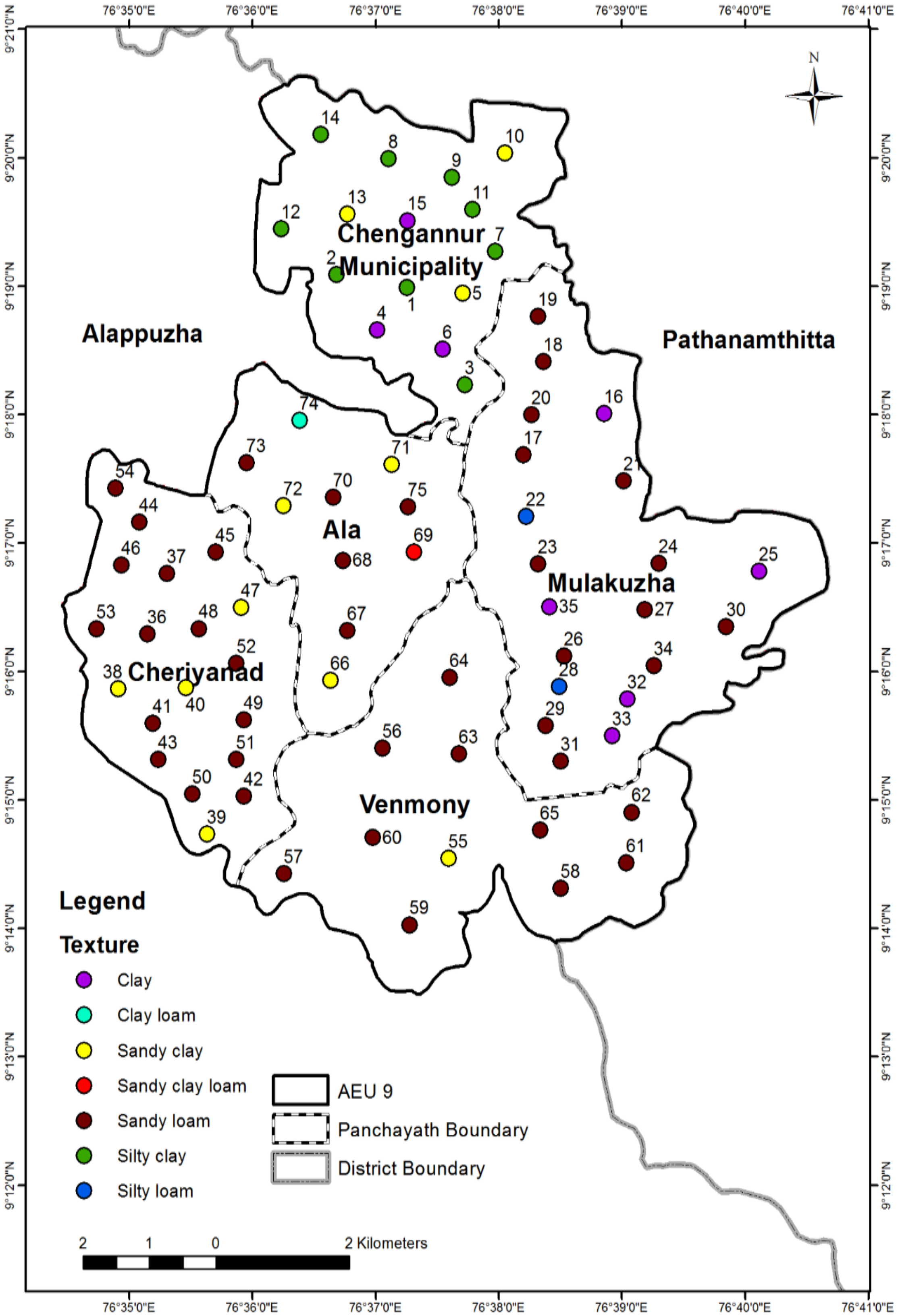


Fig 9. Spatial distribution of textural classes in the post-flood soils of AEU 9 in Alappuzha district

5.1.1.6 Maximum water holding capacity

The maximum water holding capacity of soil ranged from 32.1 to 74.6 percent with a mean value of 47.7%. Majority of soils (70%) had WHC below 30%, followed by 20% of the soils with between 30 and 50 per cent and 10 per cent of soils in the range of 50 to 70 per cent (Fig 9).

Water holding capacity was found to be the highest in Chengannur soils where high clayey content was observed and soil texture was silty clay. 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 water stable aggregates and clay content but negatively correlated with sand content of soil.

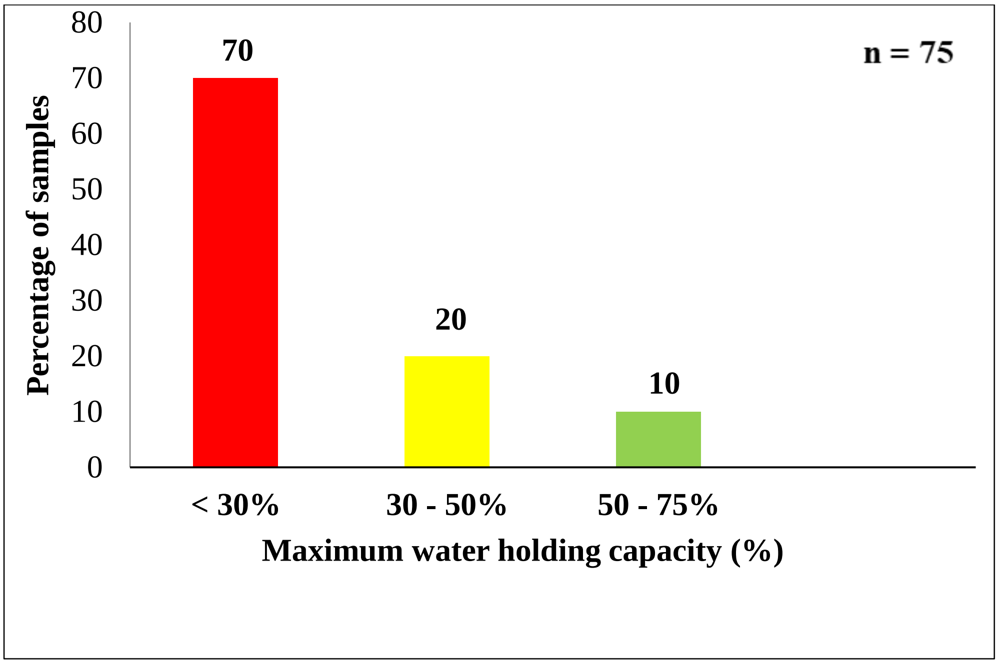


Fig 10. Frequency distribution of maximum water holding capacity in the post-flood soils of AEU 9 in Alappuzha district

5.1.1.7 Soil moisture content

The moisture content of soils of AEU 9 varied between 11.3 and 24.4 per cent with a mean value of 17.9%. Moisture content of soil is influenced by the clay and organic matter content of the soil. Increased moisture content in soil is attributed to the increased clay and organic matter content. Majority (80.1%) of soils registered moisture content between 15 and 25 percent (Fig 10). Njoku and Okoro (2015) also reported a similar increase in moisture content after flood as a result of accumulation of clay particles that were brought to soil by the flood.

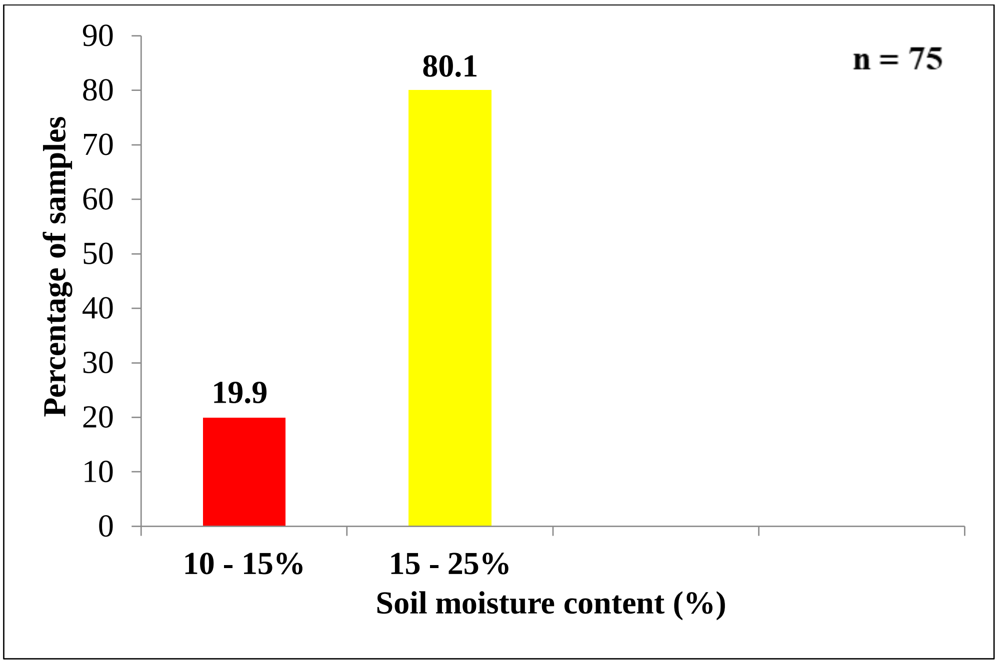


Fig 11. Frequency distribution of soil moisture content in the post-flood soils of AEU 9 in Alappuzha district

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. This is attributed to the stabilization of aggregates through the binding action of increased clay and organic carbon content in soils (Bissonnais,1996 and Amezketa,1999). The mean weight diameter is a measure of aggregate stability of soil which ranged from 0.21 to 1.02 mm with a mean value of 0.61mm. Percent of water stable aggregates varied between 37.3 and 70.6 percent with a mean of 50.1%.

Mean weight diameter of 78.7 per cent soils were <1 mm (Fig.11). Frequency distribution of water stable aggregates is given in Fig.12. The higher aggregate stability might be due to high amount of clay and organic matter which acts as cementary agent favouring aggregation. This is also evident from the positive and significant correlation of WSA with clay and organic matter content. Similar findings were reported by Kirk *et al*. (2013) and Njoku *et al.* (2011).

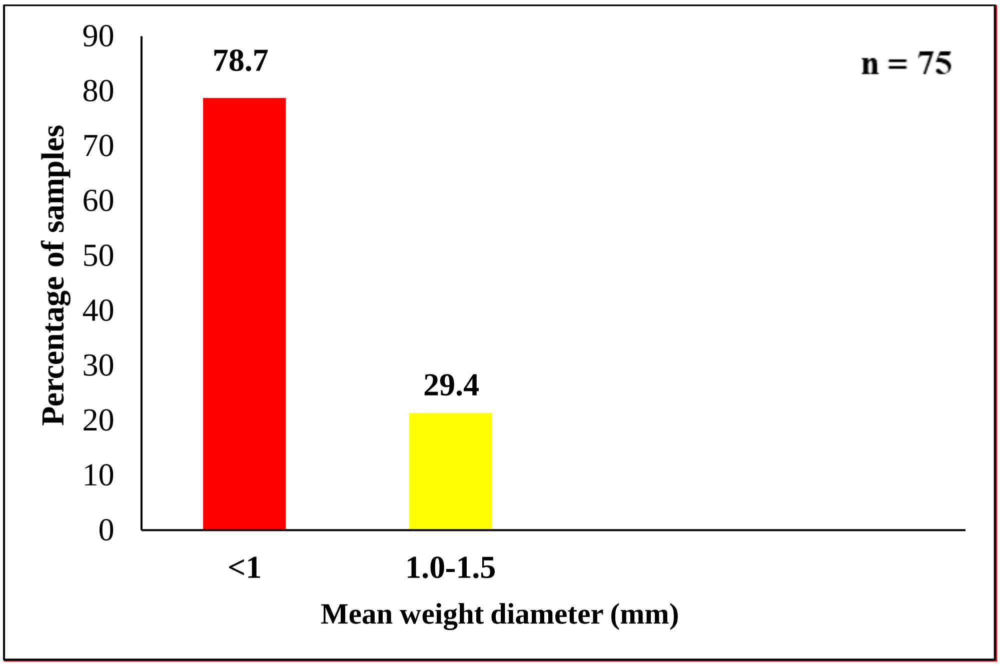


Fig 12. Frequency distribution of mean weight diameter in the post-flood soils of AEU 9 in Alappuzha district

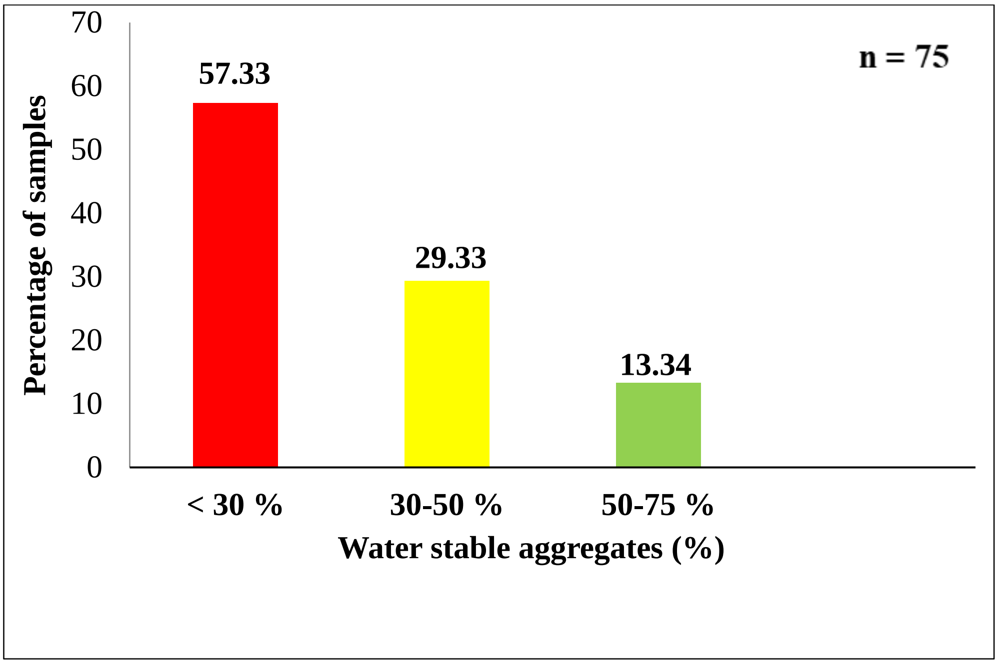


Fig13. Frequency distribution of water stable aggregates in the post-flood soils of AEU 9 in Alappuzha district

5.1.2 Chemical attributes

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

5.1.2.1 Soil pH

The present investigation revealed that soil pH varied from 4.10 to 6.90 with a mean value of 5.02. Chandran *et al.,* (2005) indicated that the soils of Kerala were mostly laterites and basically acidic in reaction. The GIS generated thematic map of soil pH is depicted in Fig.14. Majority of soils (90.3%) were in the extremely acidic to strongly acidic category (Fig 13). 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 concentrations of basic cations like K and Ca were observed to be higher. An increase in percent of soils with extreme acid pH in post flood soils (20%) compared to pre-flood indicating leaching of basic cation from soils (Appendix IV). This is also evident from the deficient levels of calcium (63.9%) and magnesium (100%) observed in these soils. Similar results were reported by Akpovete *et al.*, (2014).

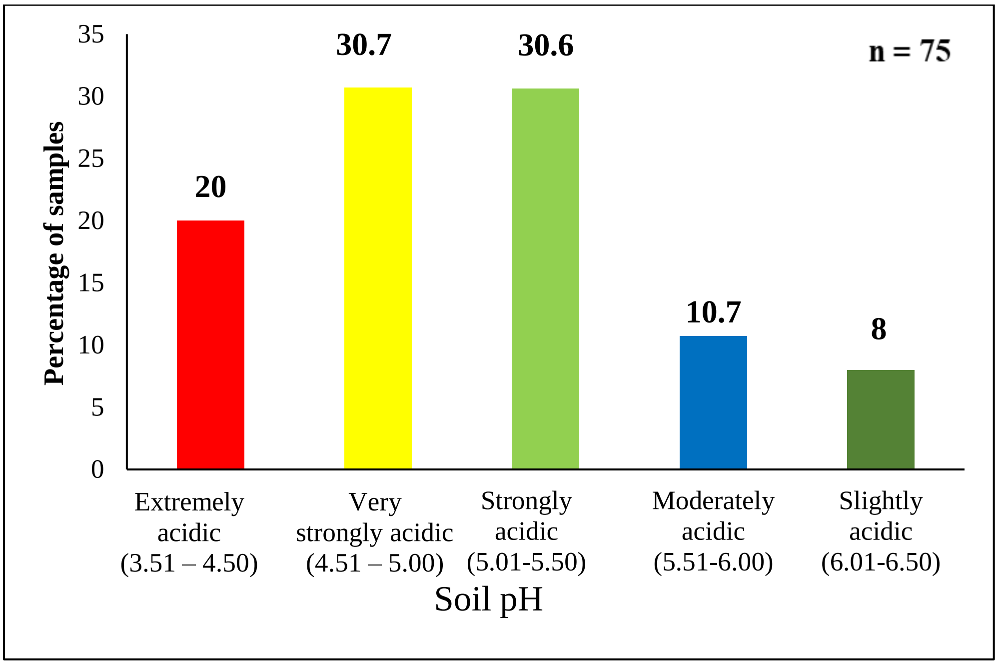


Fig 14. Frequency distribution of soil pH in post-flood soils of AEU 9 in Alappuzha district

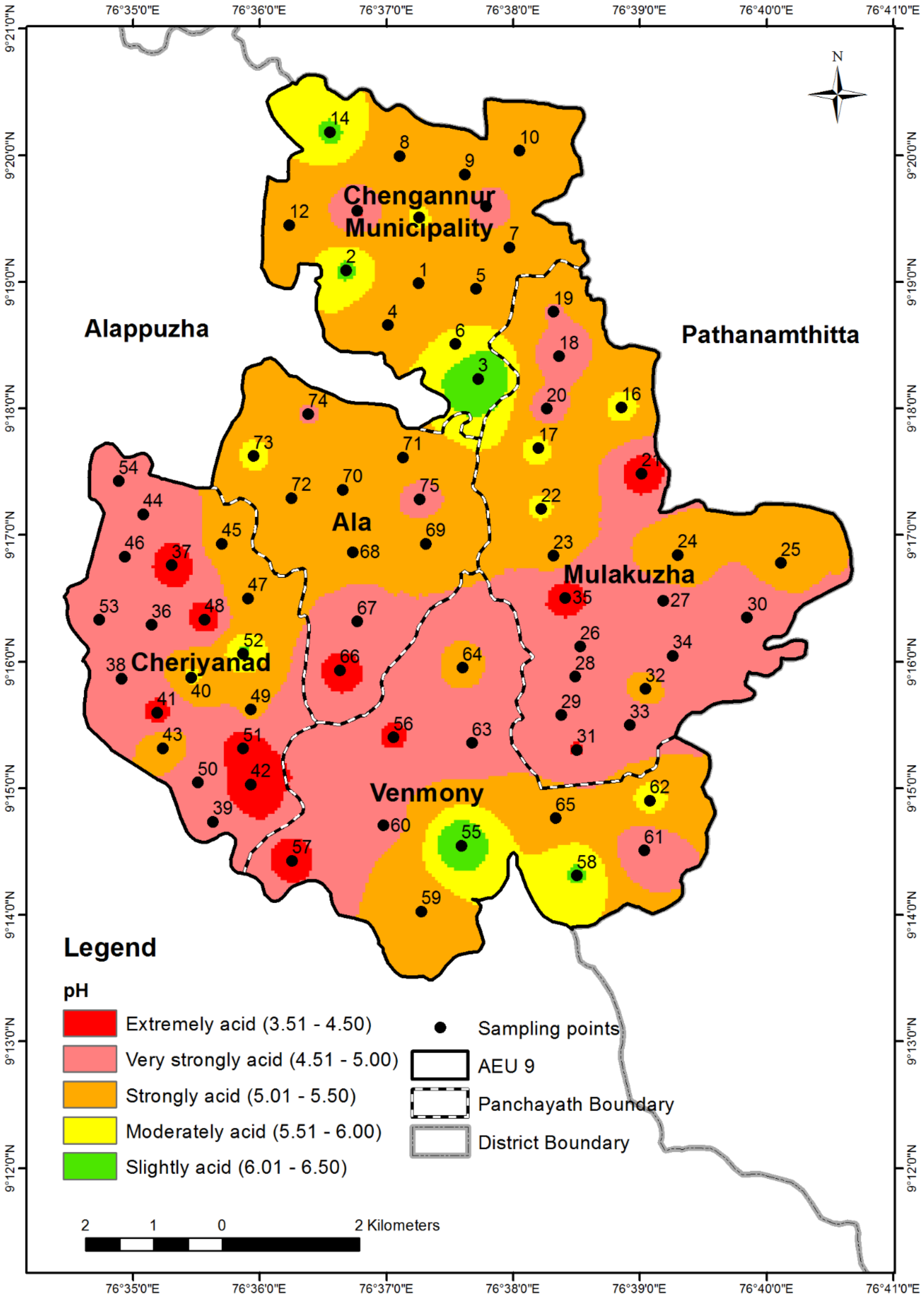


Fig15. Spatial distribution of soil pH in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.2 Exchangeable acidity

Exchangeable acidity of soils ranged from 1.00 to 3.00 c mol g $^{-1}$ and majority of soils (75 %) lies in the 1.00 - 2.00 c mol g $^{-1}$ range and the rest in 2.00 - 3.00 c mol g $^{-1}$ range (Fig.16).

The low pH of the soils might have resulted in increased exchangeable acidity. Thus soil pH was inversely related with exchangeable acidity. A negative correlation was also observed between soil pH and exchangeable acidity in the present study. Similar results were reported by Shalimadevi and Anikumar (2006).

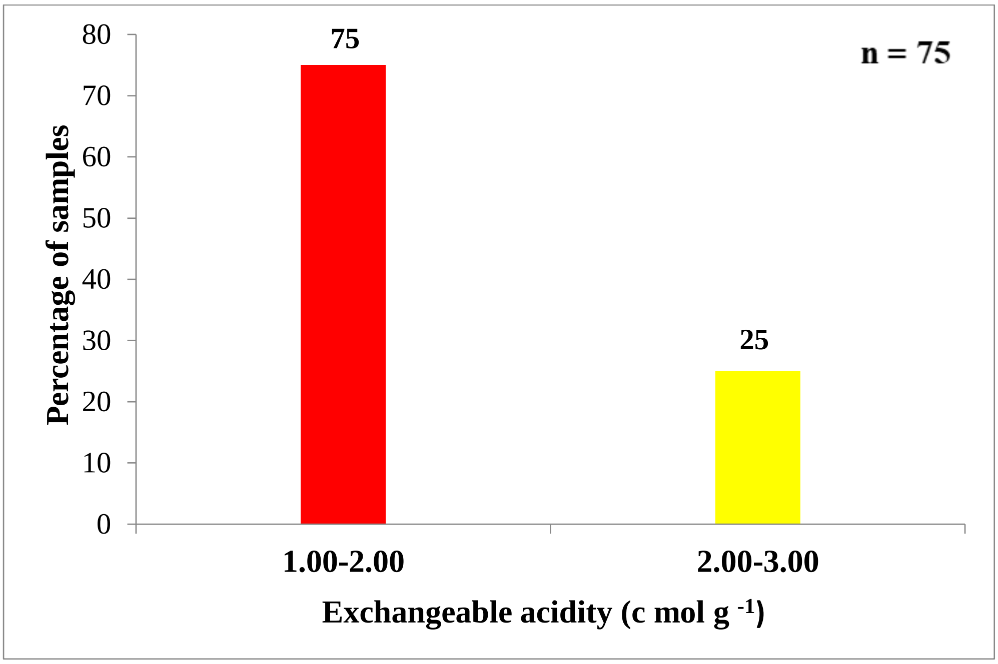


Fig 16. Frequency distribution of exchangeable acidity in post-flood soils of AEU 9 in Alappuzha district

5.1.2.3 Electrical Conductivity

Electrical conductivity of soils in the study area varied between 0.10 and 0.60 dSm^{-1}. EC was found to be less than 1dSm^{-1} in all the soils which is considered as normal range having low salinity hazards (Fig.15). 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. An inverse relationship was observed between soil pH and electrical conductivity which was quite evident from the highest EC value of 0.60 dSm^{-1} observed in Cheriyanad which again recorded the lowest pH of 4.10. The lowest mean value of EC (0.10 dSm^{-1}) was recorded in Chengannur which recorded the highest mean pH of 5.42.

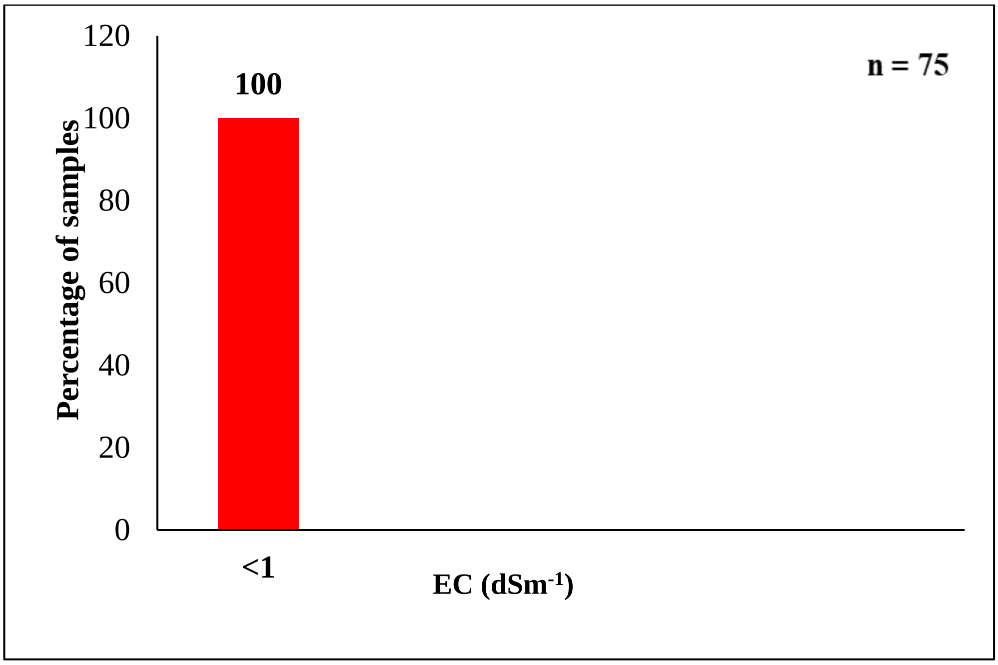


Fig 17. Frequency distribution of electrical conductivity in post-flood soils of AEU 9 in Alappuzha district

5.1.2.4 Organic carbon

Organic carbon content ranged between 0.51 and 2.62% with a mean value of 1.42%. Majority (61.3%) of the post flood soils are having medium organic carbon status followed by 38.7% soils with high status (Fig 17). Spatial variability of organic carbon in the post-flood area of AEU 9 is given in Fig 18.

An increase in organic carbon content was observed due to flooding with high organic carbon status in 18% in pre-flood soils compared to 38.7% in post flood soils. Similarly percent of soils with medium organic carbon status increased from 47% in pre-flood to 61.3% in post-flood soils. Organic carbon was high in most of the areas in

Chengannur and Mulakuzha and medium in other panchayats. This can be attributed 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 water stable aggregates, silt, clay and moisture content. Similar findings were obtained by Hoyle *et al.*, (2011) and Grybos *et al.* (2009) who observed an increase in organic carbon with the increase in clay accumulation.

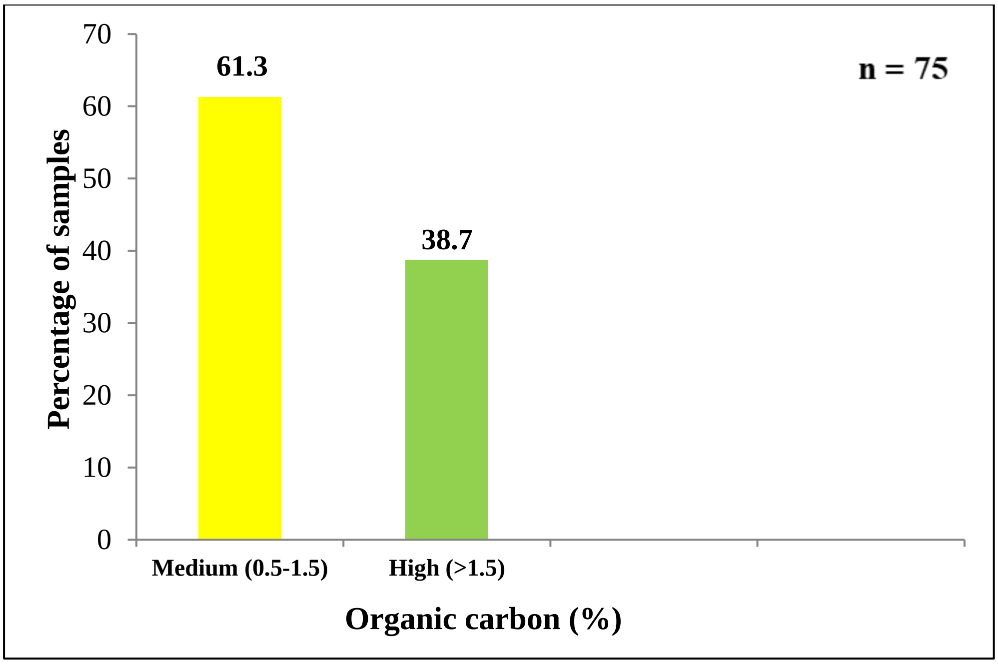


Fig 18. Frequency distribution of organic carbon in the post-flood soils of AEU 9 in Alappuzha district.

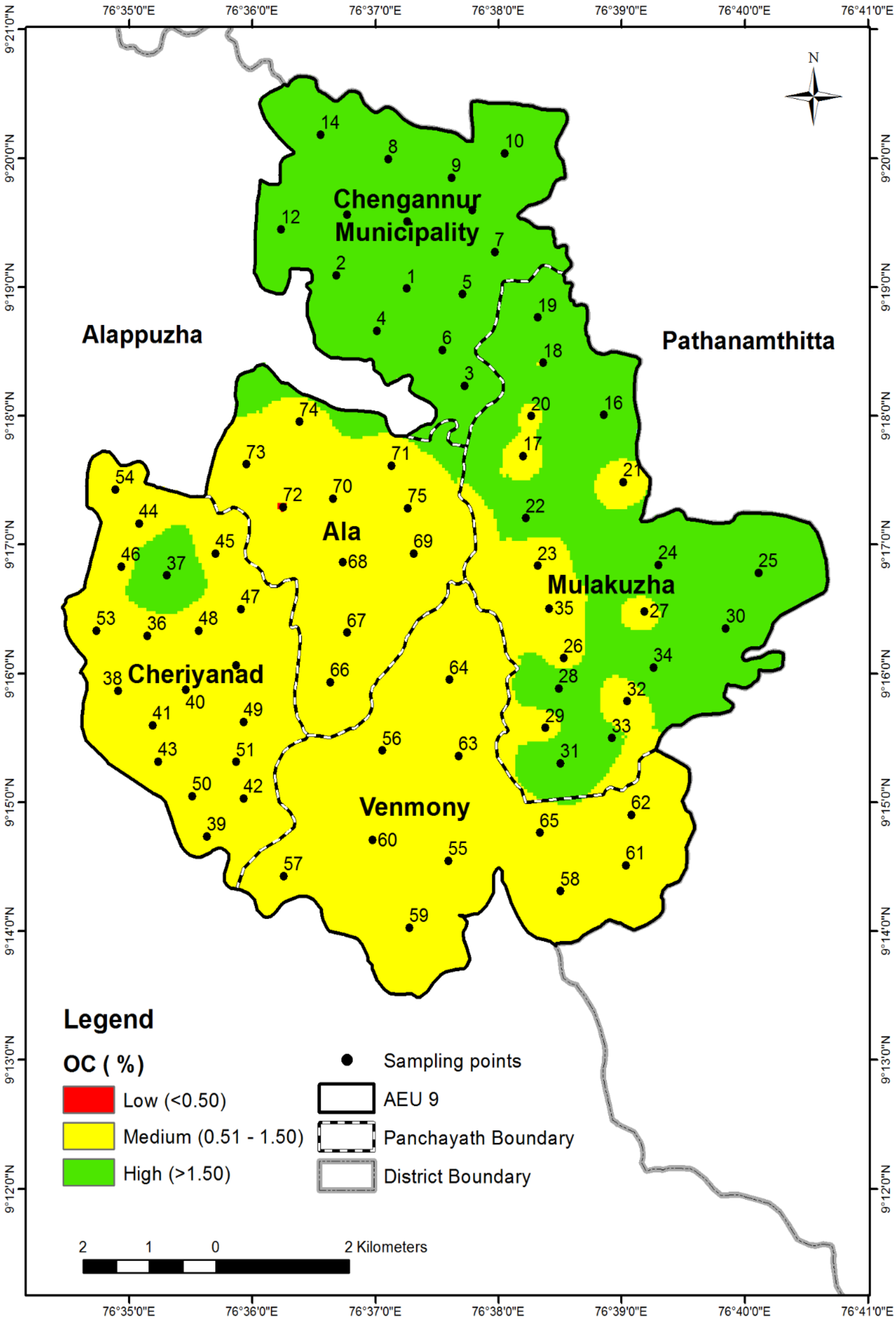


Fig19. Spatial distribution of organic carbon in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.5 Available nitrogen

The available nitrogen content of soil varied between 100 and 627 kg ha^{-1} with a mean value of 197 kg ha^{-1}. Available nitrogen was low in 89.3% of the post flood soils and only 10.7% were in the medium range (Fig.19). The thematic map of available nitrogen is depicted in Fig.20. Available nitrogen was found to be medium in some areas of Mulakuzha, Ala and Cheriyanad panchayats and low in other areas. Even with medium to high organic carbon status of the soils under study, the low available nitrogen observed 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 nitrogen 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 nitrogen 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 nitrogen availability. Increasing soil acidity obstructs mineralization of organic matter and decreased the availability of nitrogen in soil under submerged condition (Liji, 1987).

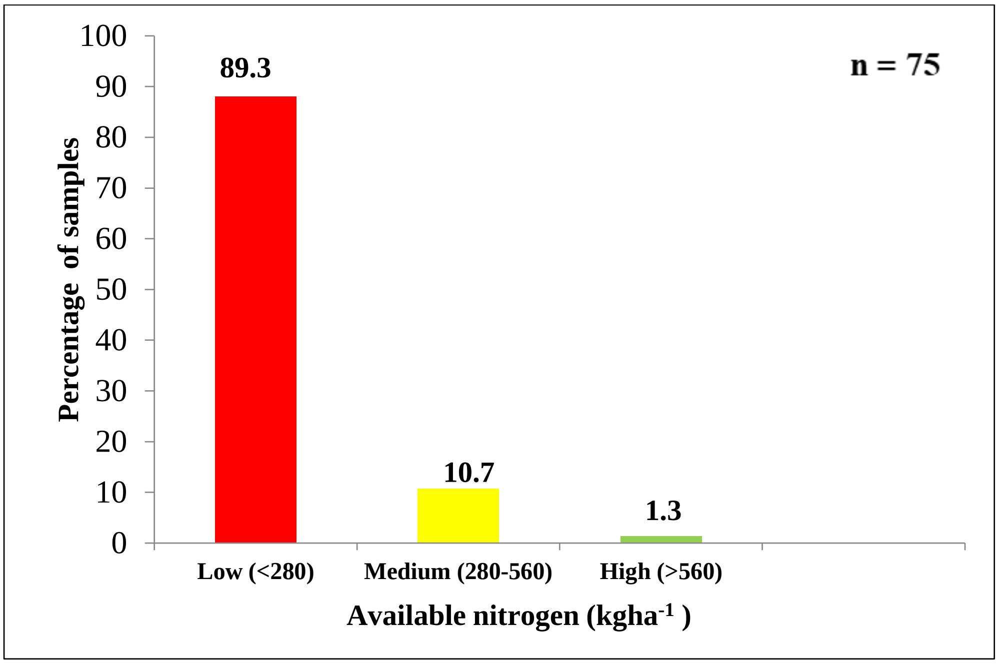


Fig 20. Frequency distribution of available nitrogen in the post-flood soils of AEU 9 in Alappuzha district

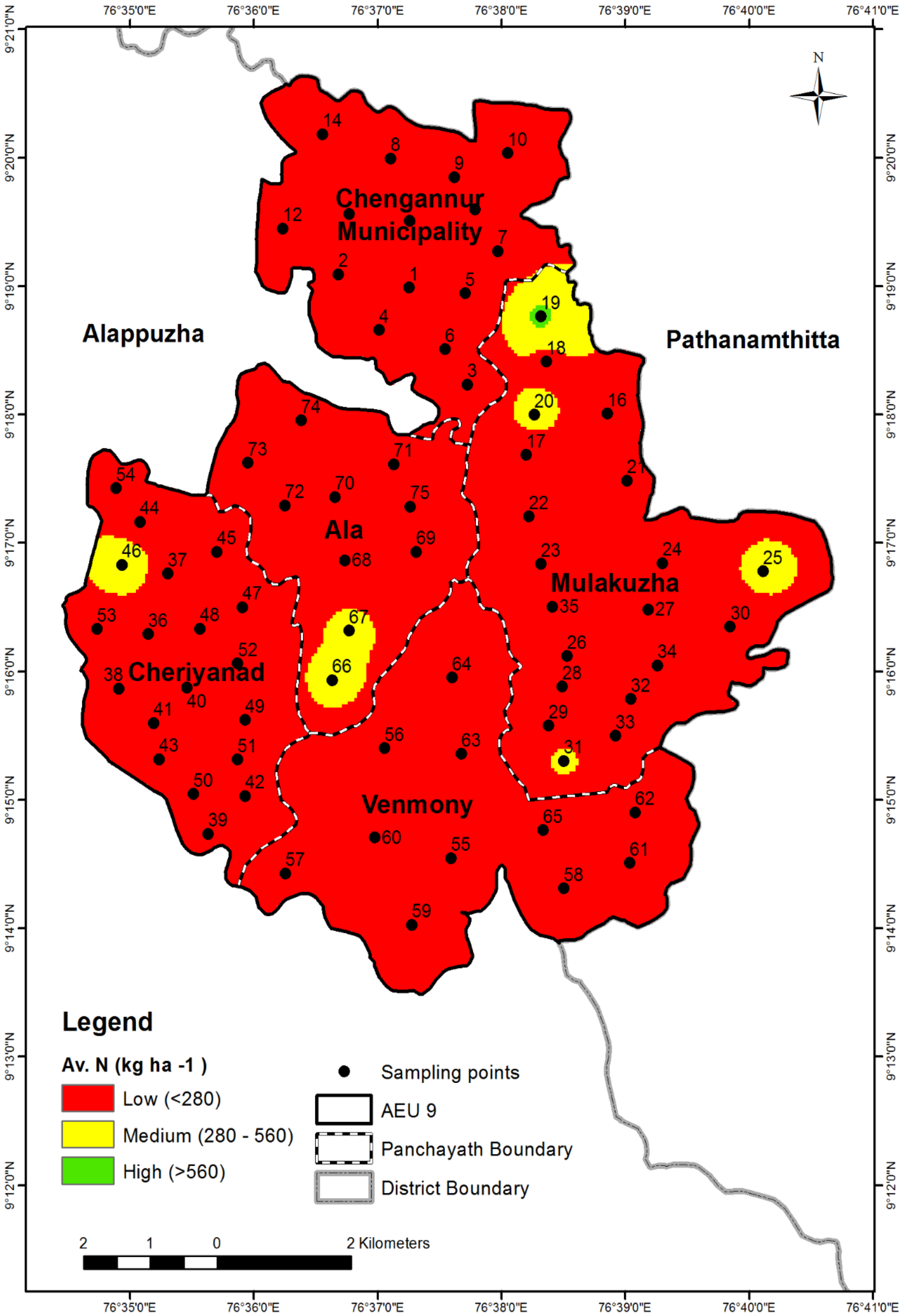


Fig 21. Spatial distribution of available nitrogen in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.6 Available phosphorous

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 phosphorous content of soil varied from 8.32 to 47.8 kg ha^{-1} and was found to be medium in 60% of the soils, high in 26.7% and low in 13.3% soils (Fig 21). Soils with medium status of available phosphorous increased in post-flood (60%) compared to pre-flood (15%) whereas high phosphorous soils decreased from 68% to 26.7% (Appendix IV).

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. It is evident from increase in soil acidity after the flood in 20% soils. Clay and organic matter deposition in the soils may have also contributed to phosphate sorption and reduction in phosphorous 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. Similar findings were observed by Beegum (2016) who reported a similar decreasing trend in phoshorous status of Kuttanad soils due to clay accumulation. Spatial distribution map of available phosphorous presented in Fig.22 revealed that available phosphorous was low in some areas of Ala and Venmony whereas it was high in Chengannur and Mulakuzha.

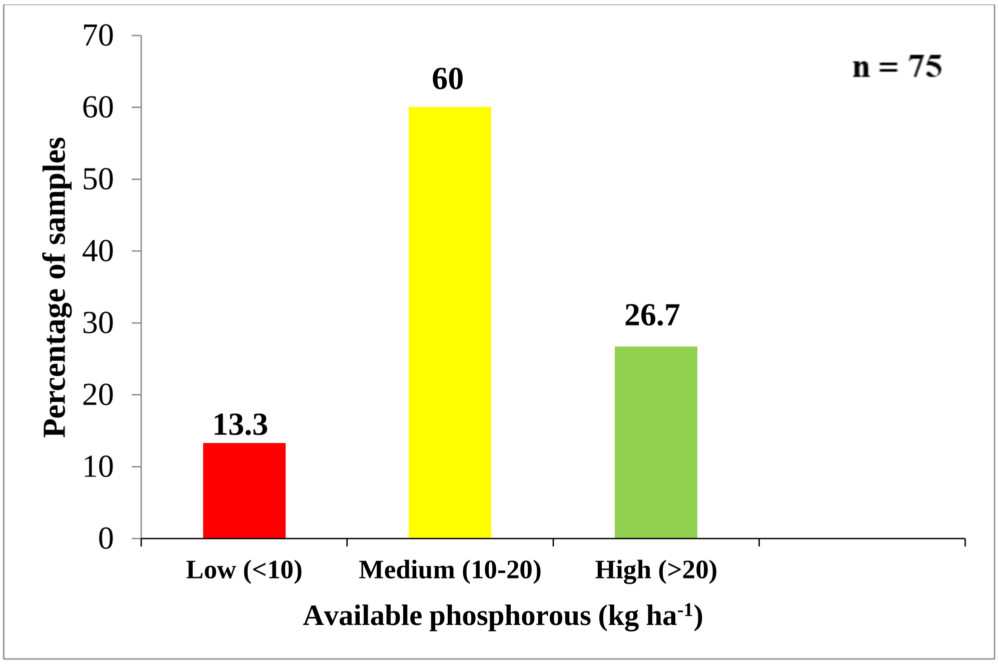


Fig 22. Frequency distribution of available phosphorous in the post-flood soils of AEU 9 in Alappuzha district.

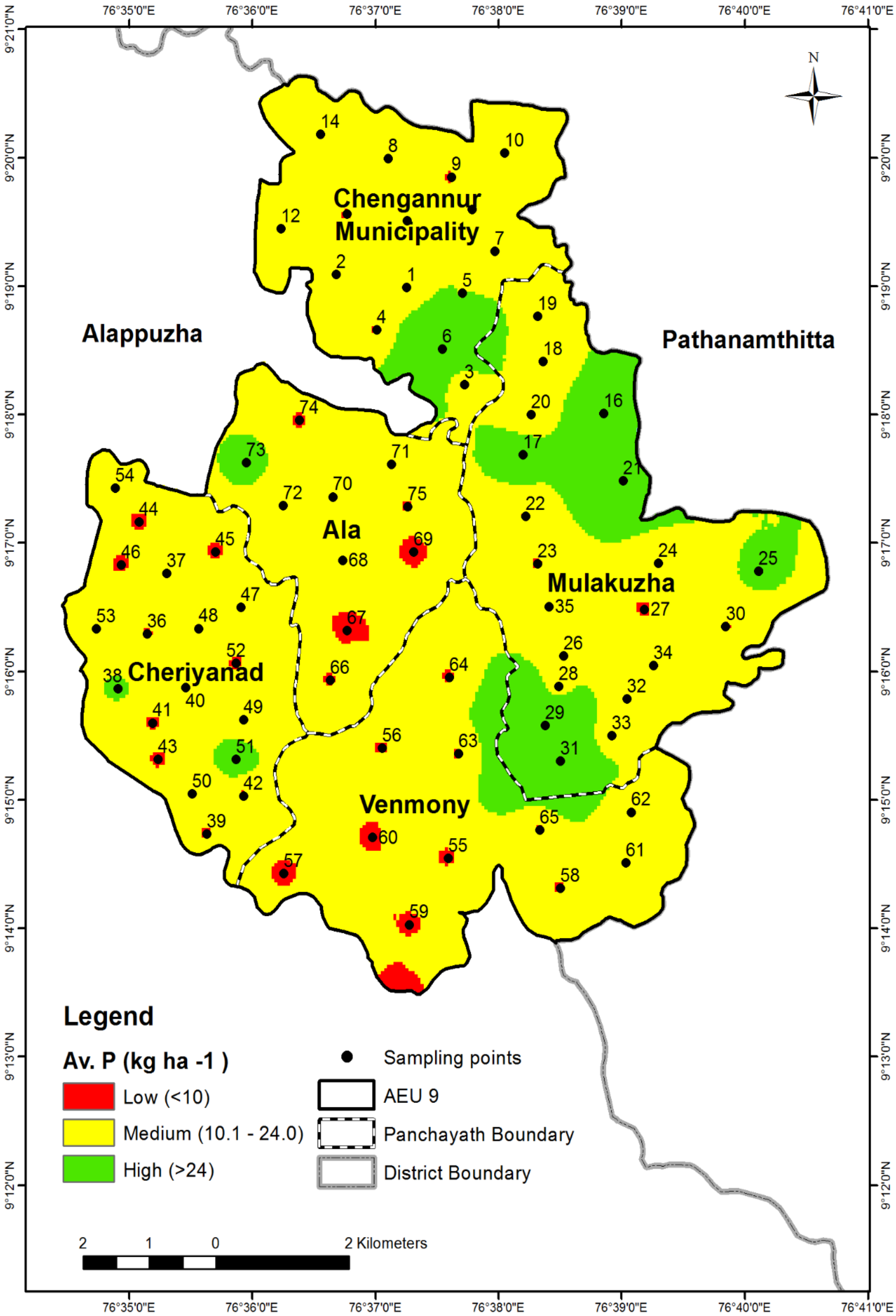


Fig 23. Spatial distribution of available phosphorous in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.7 Available potassium

The available K content in soil ranged between 100 and 492 kg ha$^{-1.}$ Majority (53.1%) of the soils were medium in available K, 44.6% were high and 2.3% low (Fig 23). Available K status in soil increased in post-flood soils compared to pre-flood soils. 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). The thematic map of available K depicted in Fig.24 showed that majority of area in Cheriyanad, Ala and Mulakuzha were high in available potassium whereas Cheriyanad and Venmony were medium in available K. Despite heavy rainfall and consequent leaching, the high available K in some of these areas could be attributed to accumulation of K bearing sediments after the flood.

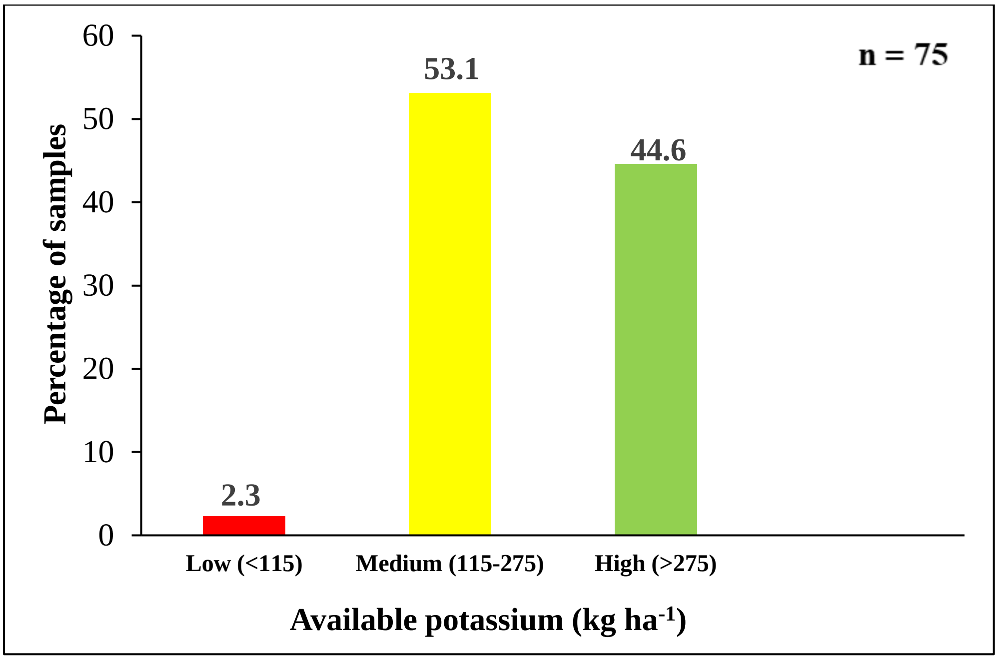


Fig 24. Frequency distribution of available potassium in the post-flood soils of AEU 9 in Alappuzha district.

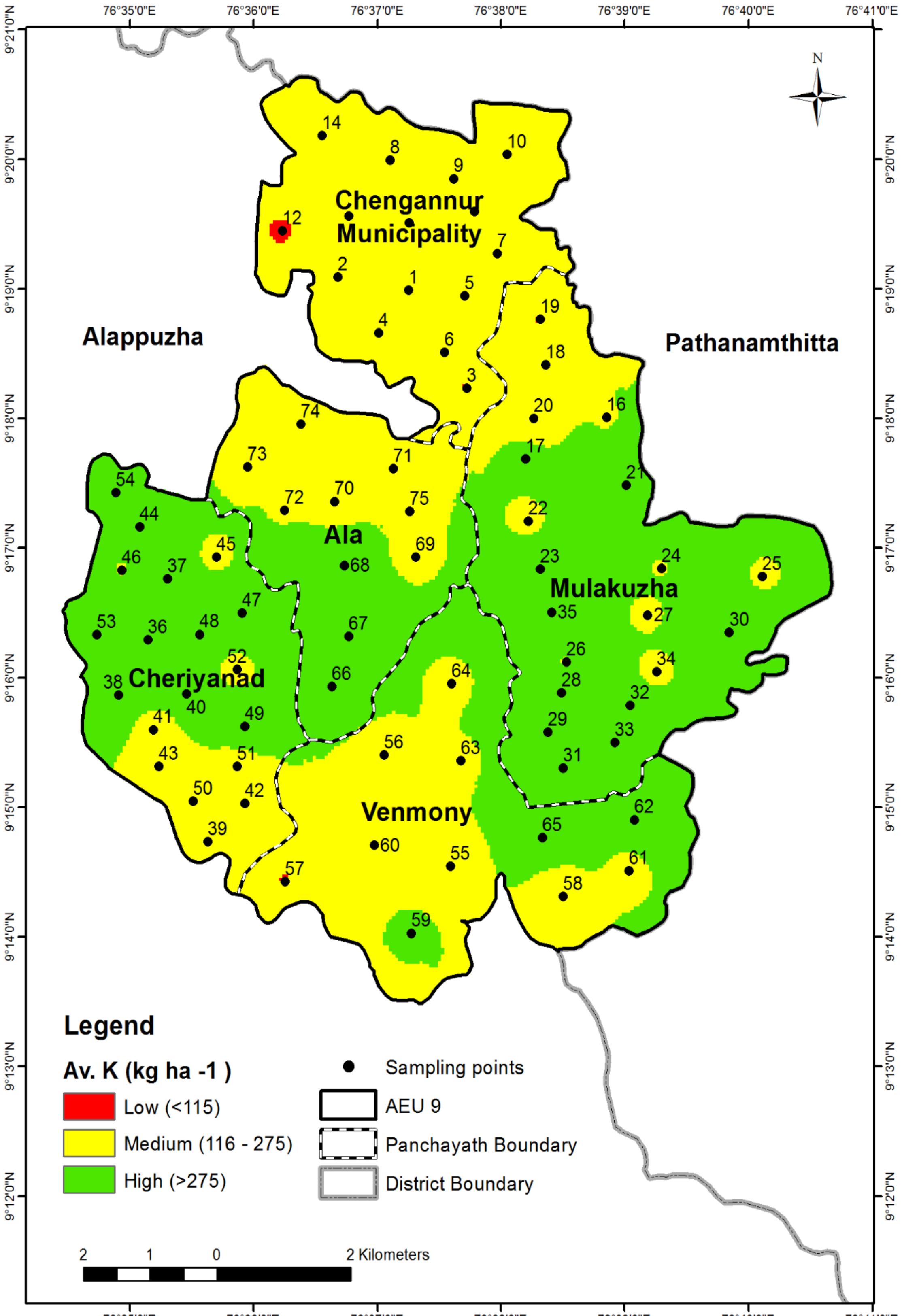


Fig 25. Spatial distribution of available potassium in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.8 Available calcium

Available calcium ranged between 110 and 478 mg kg^{-1} in the study area. Available Ca was deficient in 63.9% of post-flood soils and adequate in 36.1% but in pre flood soils 25% were deficient and 75% 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 Cheriyanad, Ala and Venmony were found to be deficient in calcium whereas Chengannur and parts of Mulakuzha were adequate in Ca. Available calcium was relatively higher in areas with sediment deposition. This is evident from the significant positive correlation of available Ca with clay content (r = 0.773**) (Fig 25).

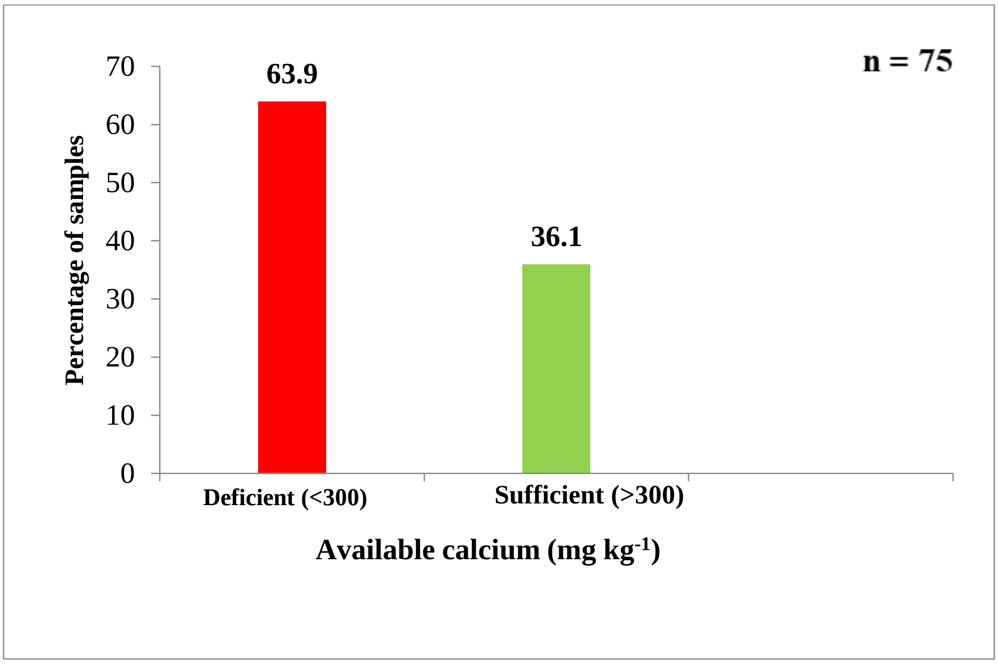


Fig 26. Frequency distribution of available calcium in the post-flood soils of AEU 9 in Alappuzha district

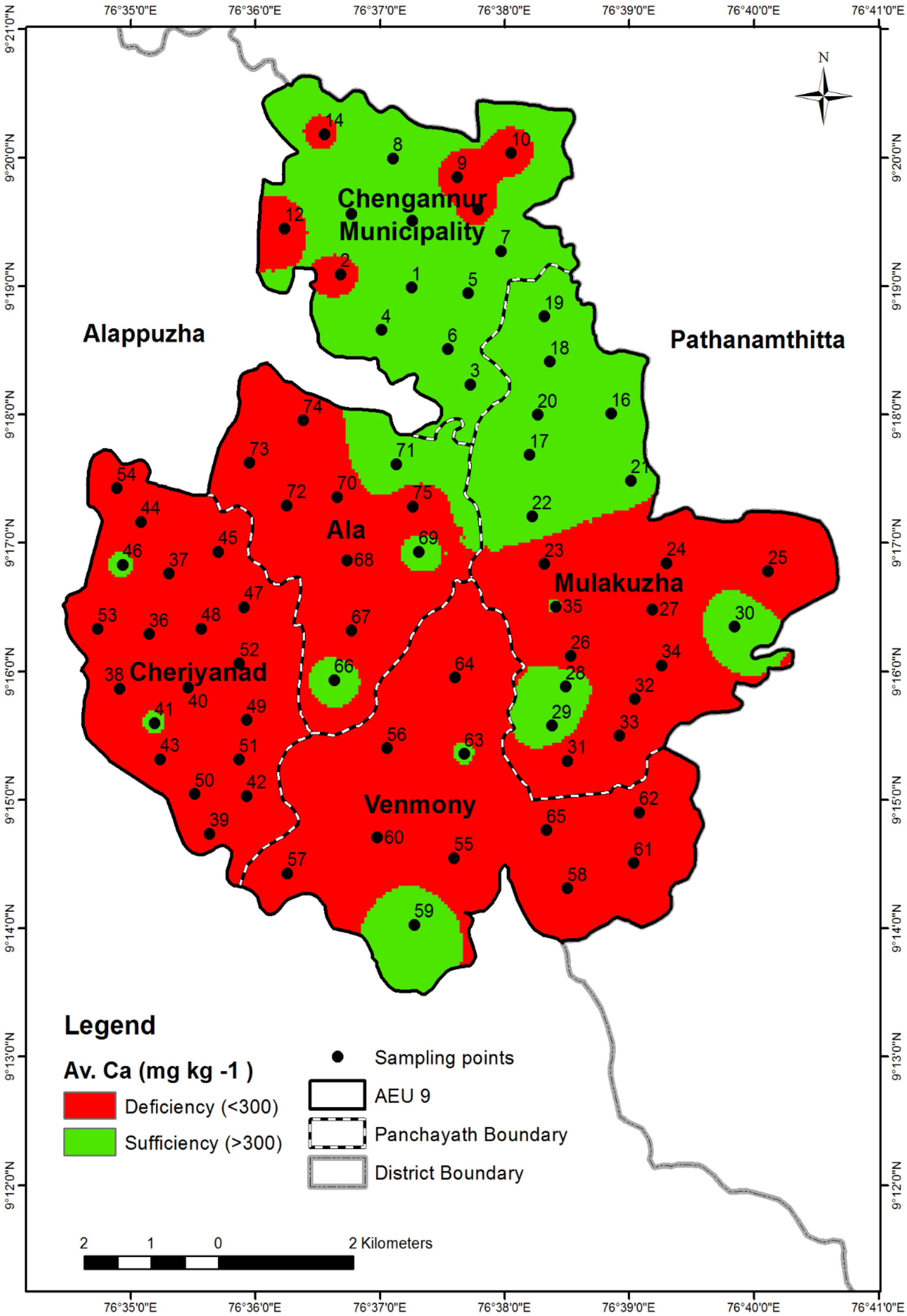


Fig 27. Spatial distribution of available calcium in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.9 Available magnesium

Available Mg varied between 46.9 and 105 mgkg^{-1}.There was a decline in available magnesium in soil due to the flood. Available magnesium was found to be deficient in 100% of the post flood soils (Fig.27) whereas it was sufficient in 95% of the pre-flood soils.

A drastic decline in concentration of available Mg in post flood soils compared to pre flood indicate heavy leaching of Mg during the flood. 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 (Edmeades *et al.*, 1985) which might be the reason for lower magnesium levels in soils despite the high calcium content observed in the same areas. Similar findings were also reported by Natarajan *et al*. (2013).

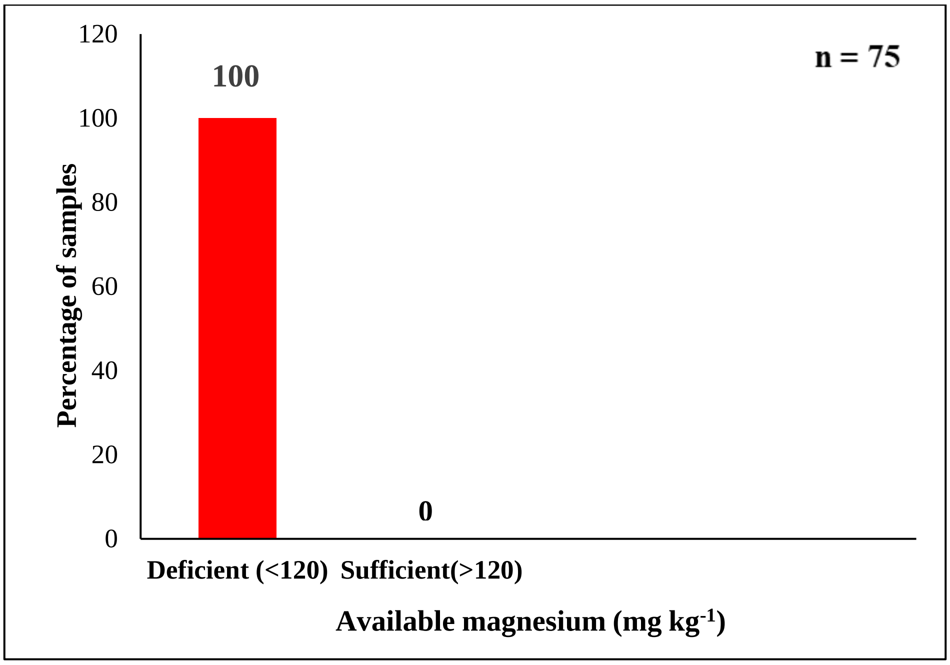


Fig 28 Frequency distribution of available magnesium in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.10 Available sulphur

Available sulphur content in soil varied between 3.02 and 27.5 mgkg^{-1}and was found to be adequate in 93.3% soils (Fig.28). The higher levels of available sulphur might be due to the accumulation of organic matter and sediments in these soils. Available S was significantly and positively correlated with particle density and 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 sulphur levels in soil.

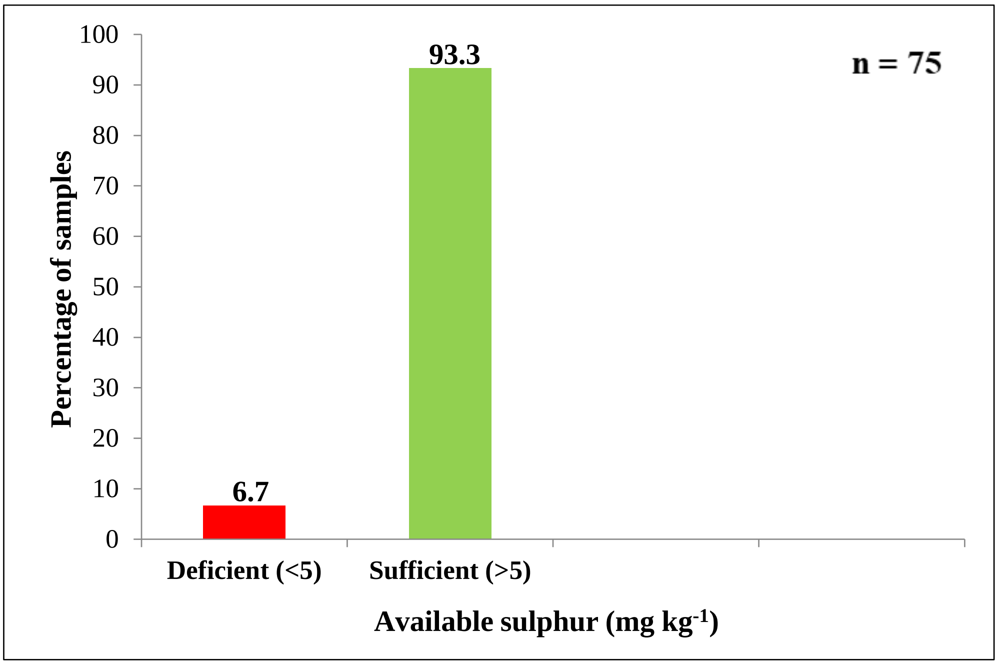


Fig 29. Frequency distribution of available sulphur in the post-flood soils of AEU 9 in Alappuzha district

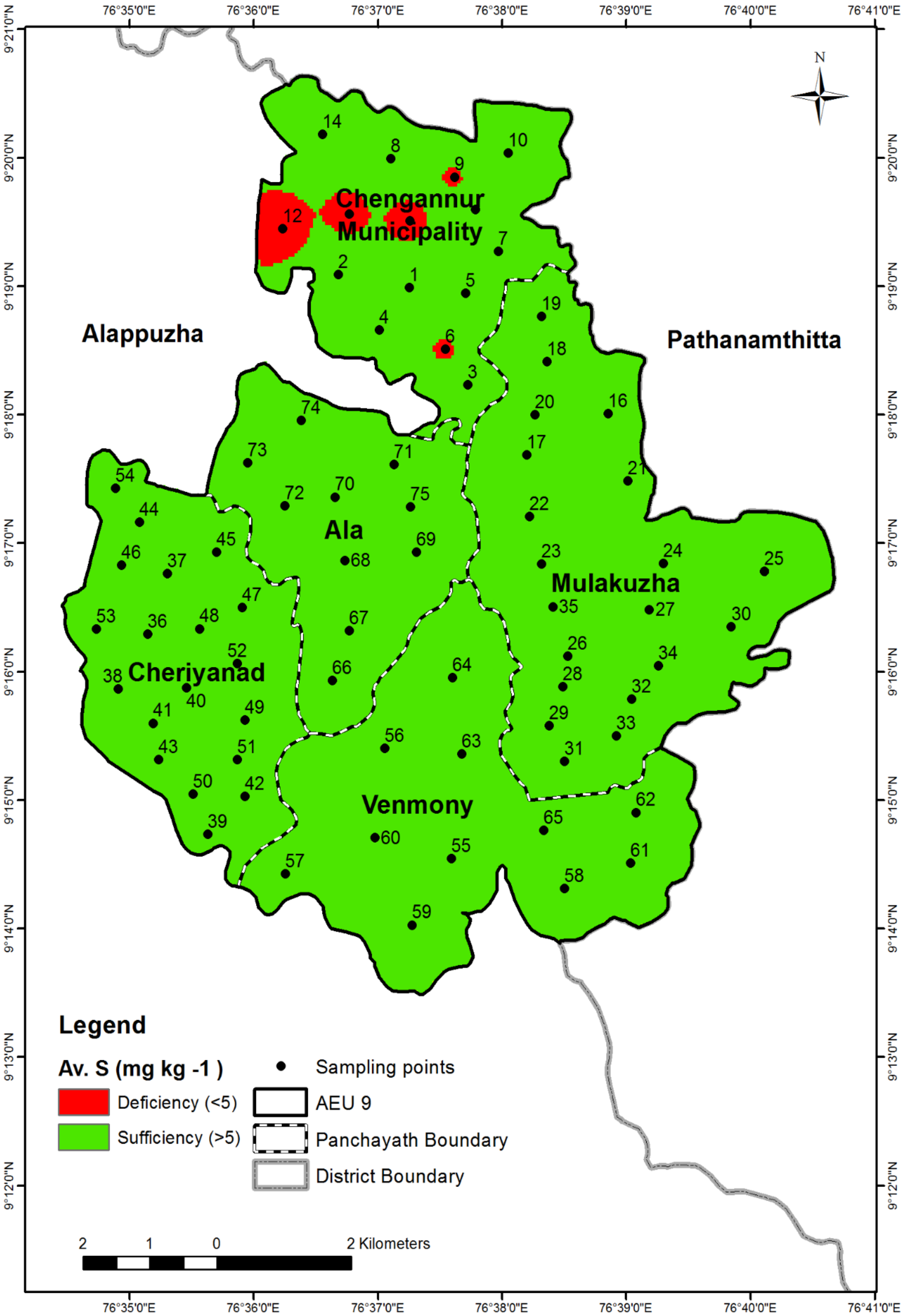


Fig 30. Spatial distribution of available sulphur in the post-flood soils of AEU 9 in Alappuzha district

5.1.2.11 Available boron

Available boron in soil ranged between 0.01 and 0.41 $mgkg^{-1}$. Available B was deficient in all the soils of AEU 9 before and after the flood (Fig.30). 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 boron by leaching (Mengel *et al.,* 2011).

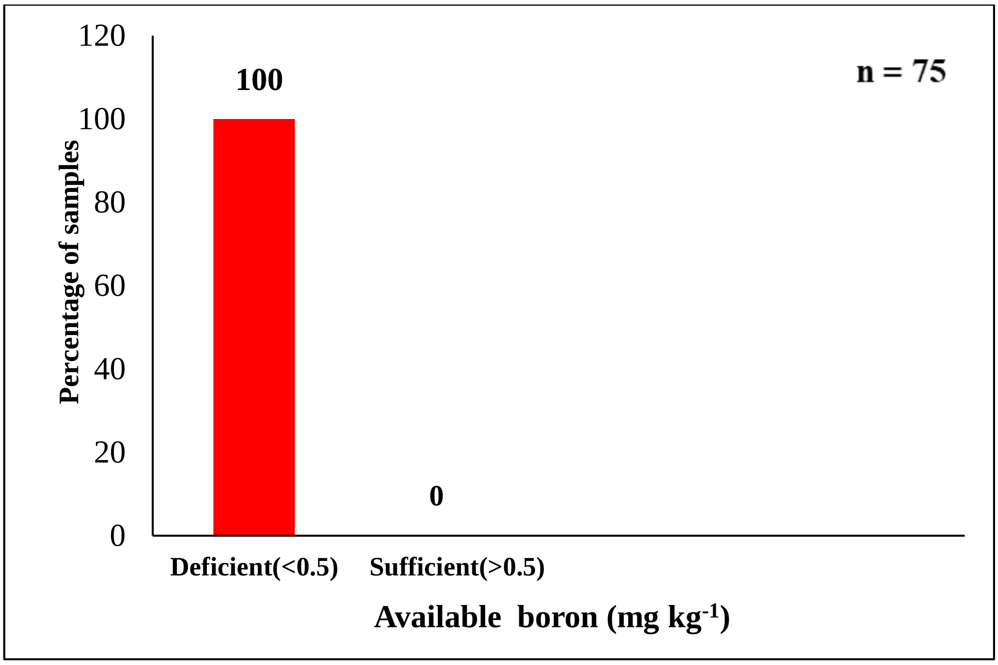


Fig 31. Frequency distribution of available boron in the post-flood soils of AEU 9 in Alappuzha district.

5.1.3. Biological attributes

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

5.1.3.1 Acid phosphatase activity

Acid phosphatase activity in soil ranged between 16.02 and 37.85 µg PNP produced g soil^{-1}h^{-1}. Majority (76 percent) of soils recorded an acid phosphatase activity between 25 and 50 µg PNP produced g soil^{-1}h^{-1} (Fig 31). The improved organic matter in soils can improve microbial and enzyme activity. Increased enzyme activity observed can be attributed to the improved organic matter status in these 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 4.1-6.90 which was found favourable for phosphatase enzyme activity.

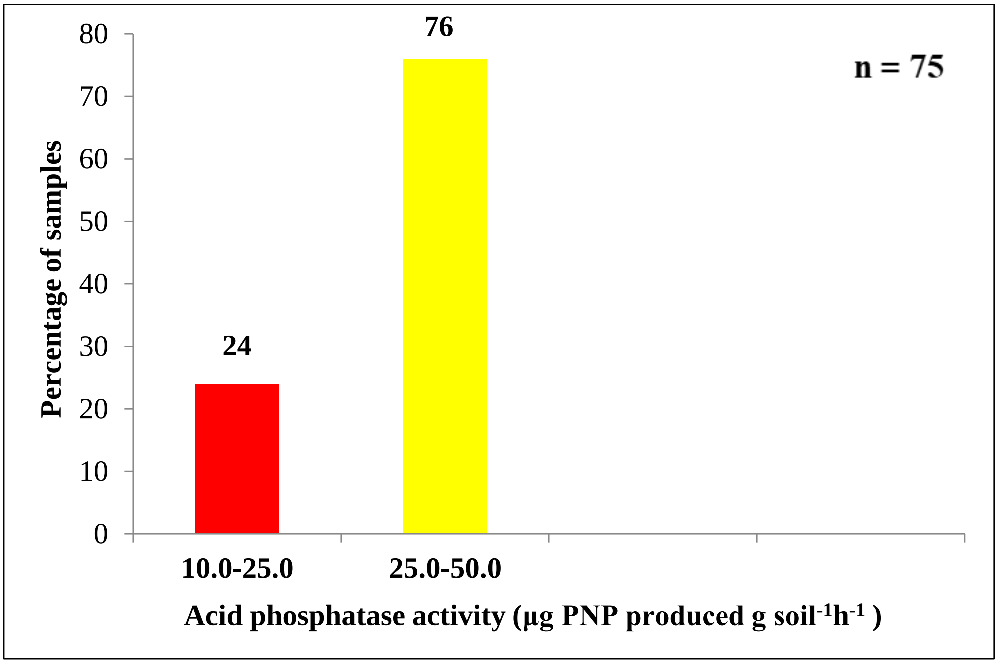


Fig 32 Frequency distribution of acid phosphatase activity in the post-flood soils of AEU 9 in Alappuzha district

5.1.3.2 Dehydrogenase activity

Dehydrogenase activity in soil varied between 13.1 and 27.3 µg TPF hydrolysed g^{-1}soil 24 hr^{-1} in the post-flood area of AEU 9. Majority (64 percent) of soils registered dehydrogenase activity between 25 and 50 µg PNP produced g $soil^{-1}h^{-1}$ (Fig 32).

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 (11.3-24.4%) after the flood might have increased the dehydrogenase activity in these soils.

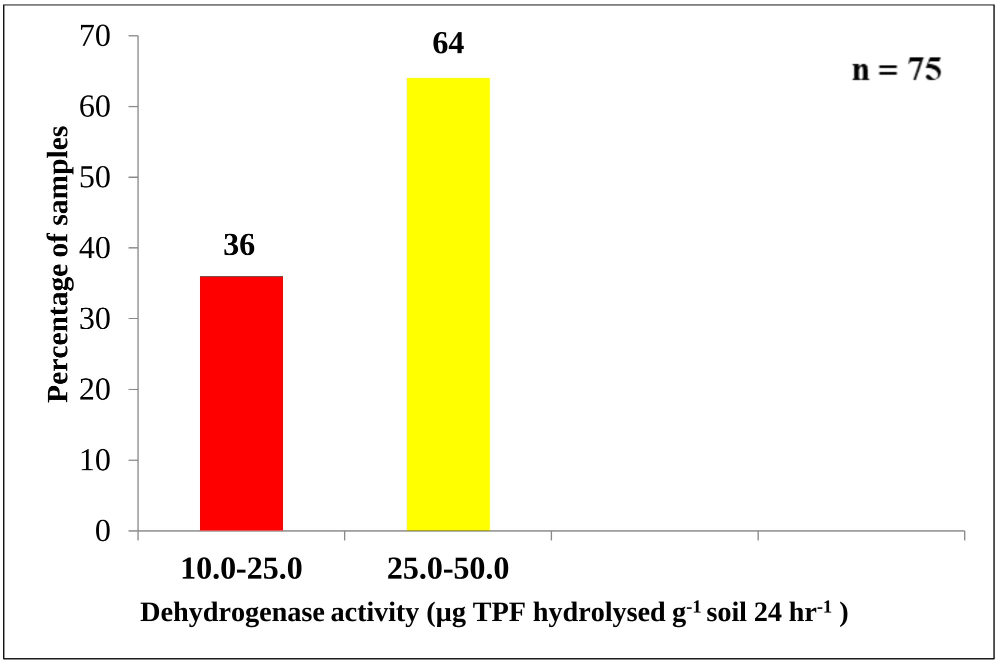


Fig 33. Frequency distribution of dehydrogenase activity in the post-flood soils of AEU 9 in Alappuzha district

5.2 SOIL QUALITY INDEX

Soil quality index of the post-flood soils of AEU 9 was calculated from eight parameters of minimum data set viz., available N, available P, available K, available Ca, available S, electrical conductivity, bulk density, clay percent and sand percent. Relative soil quality index of the soil ranged between 32.5 and 62.5%. Majority of the soils (80 %) had poor soil quality while 20 percent of soils had medium soil quality

(Fig.33). Soil quality was observed to be maximum in Chengannur and Mulakuzha where organic carbon, available nitrogen, phosphorous, potassium and calcium were found to be high and sediment depositions of clay and silt were observed. Spatial distribution of soil quality is presented in Fig 34. The contribution of organic carbon and available nutrient status to soil quality is substantial as the important indicators of soil quality index. The low to medium soil quality of AEU 9 may be attributed to the inherent properties of laterite soils, type of vegetation and micro climate as reported by Nair *et al*. (2013).

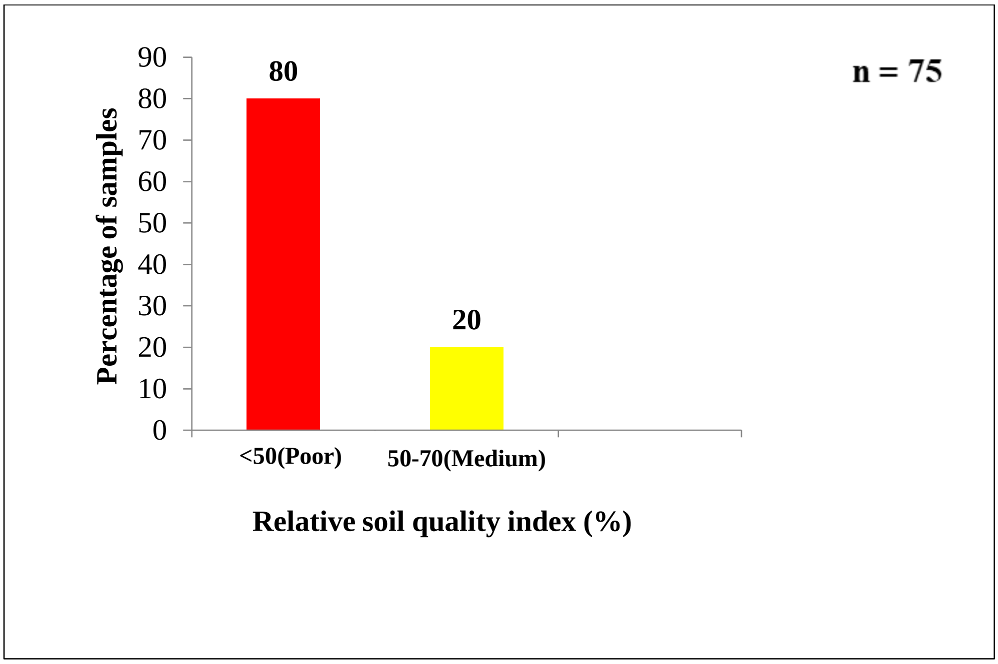


Fig 34. Frequency distribution of RSQI in the post-flood soils of AEU 9 in Alappuzha district

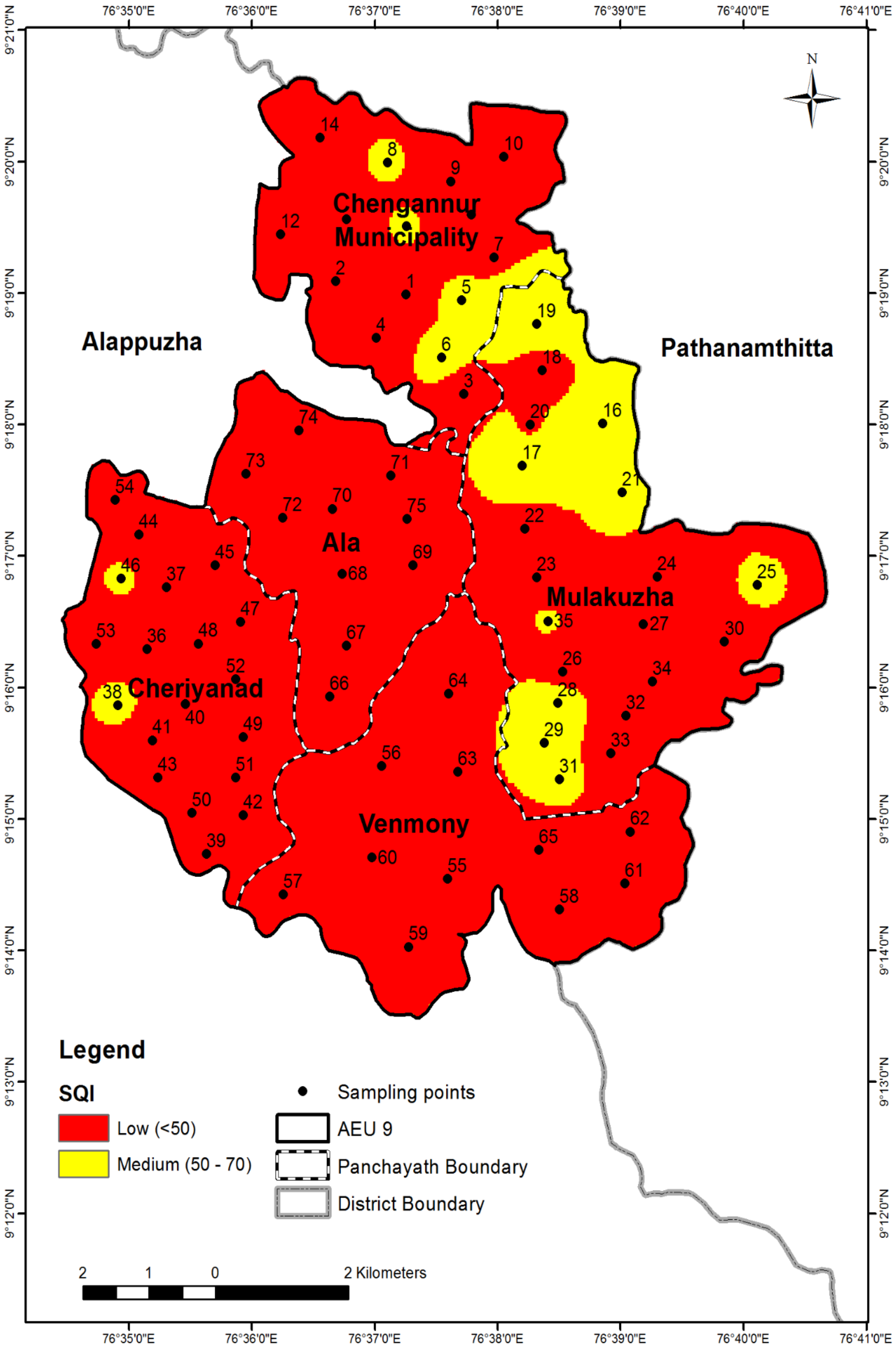


Fig 35. Spatial distribution of SQI in the post-flood soils of AEU 9 in Alappuzha district

5.3 NUTRIENT INDEX

Nutrient Index was worked out for organic carbon, available nitrogen, phosphorous and potassium contents in soil. Soil nutrient index in terms of organic carbon was found to be medium in all the five panchayaths (Fig.35). This can be attributed to the deposition of sediments rich in organic matter under the inflow of flood water and accumulation of clay. The results are in line with the findings of Grybos *et al*. (2009). Fertility status of the soil in terms of nutrient index of nitrogen was rated low in all panchayaths (Fig.36). 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). The nutrient index of phosphorous was medium in all panchayaths with the exception of Venmony which recorded only a low status (Fig.37). This is attributed to low pH, phosphate sorption and also fixation of soluble inorganic P in the soils Sah and Mikkelsen (1989). A high nutrient index of potassium was observed in Mulakuzha and Venmony panchayaths whereas it was medium in other panchayaths (Fig.38). This may be due to the accumulation of sediments as reported by Kalshetty *et al*. (2012).

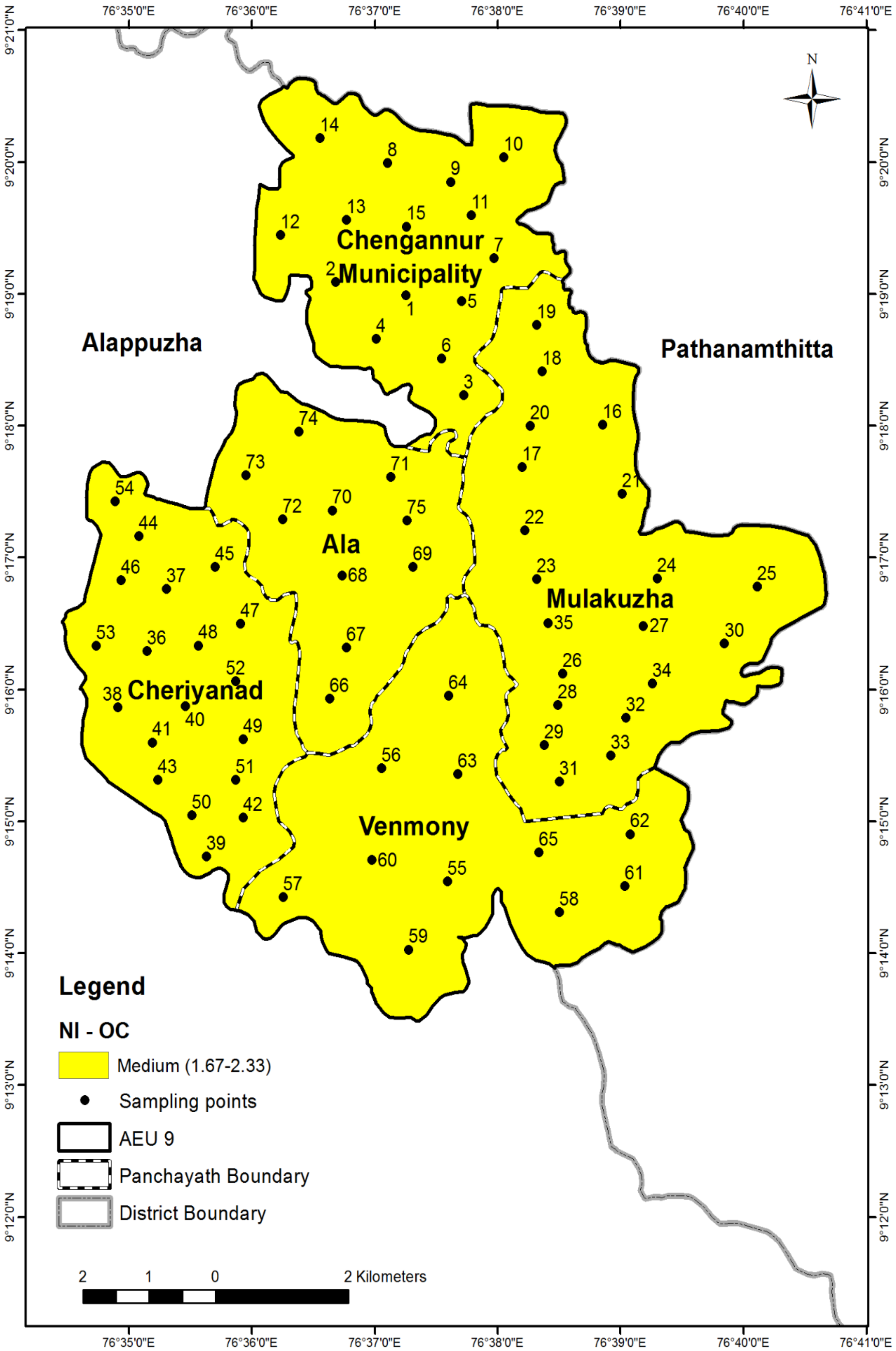


Fig 36. Spatial variability of NI-OC in the post-flood soils of AEU 9 in Alappuzha

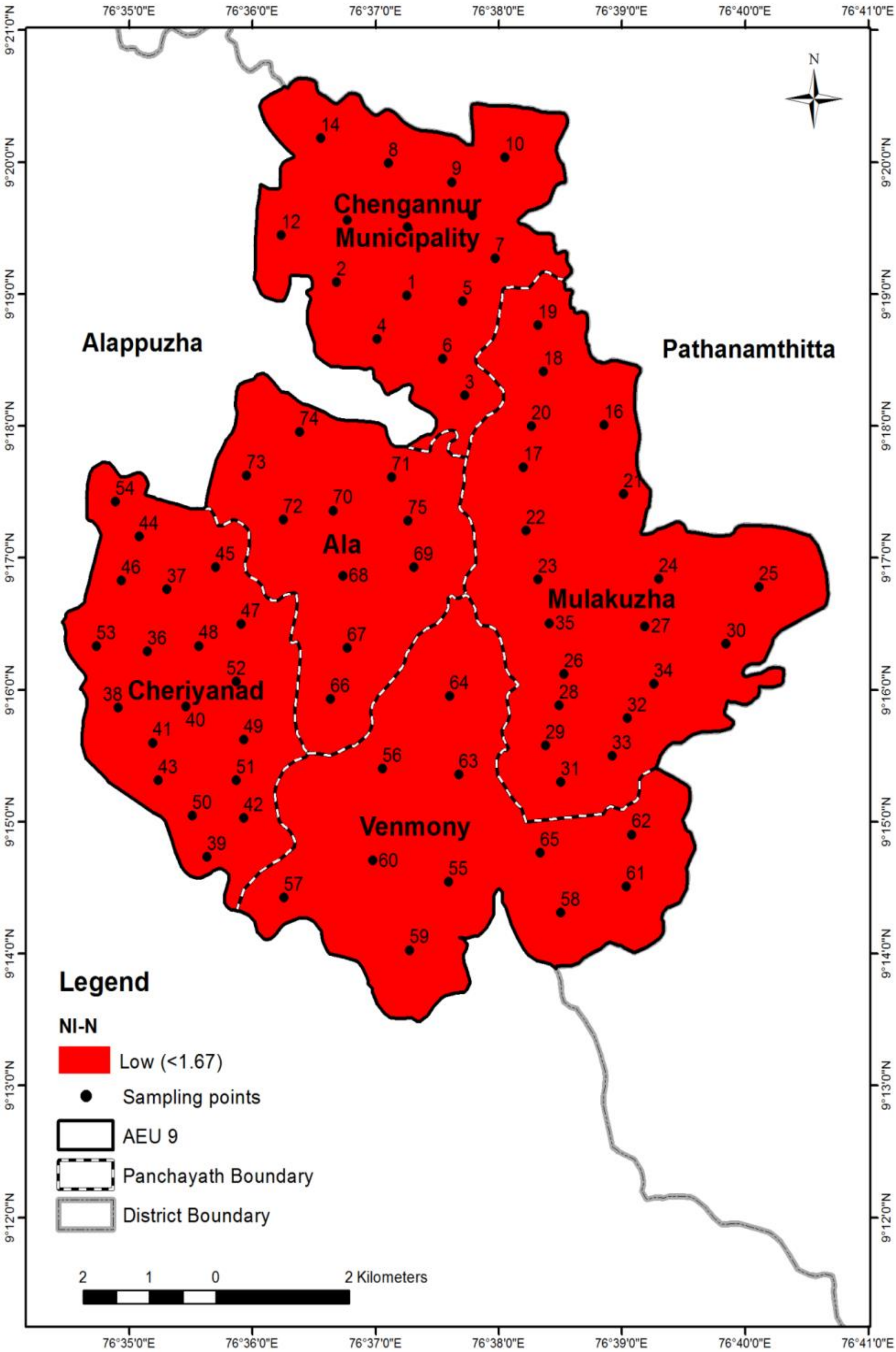


Fig 37. Spatial variability of NI-N in the post-flood soils of AEU 9 in Alappuzha

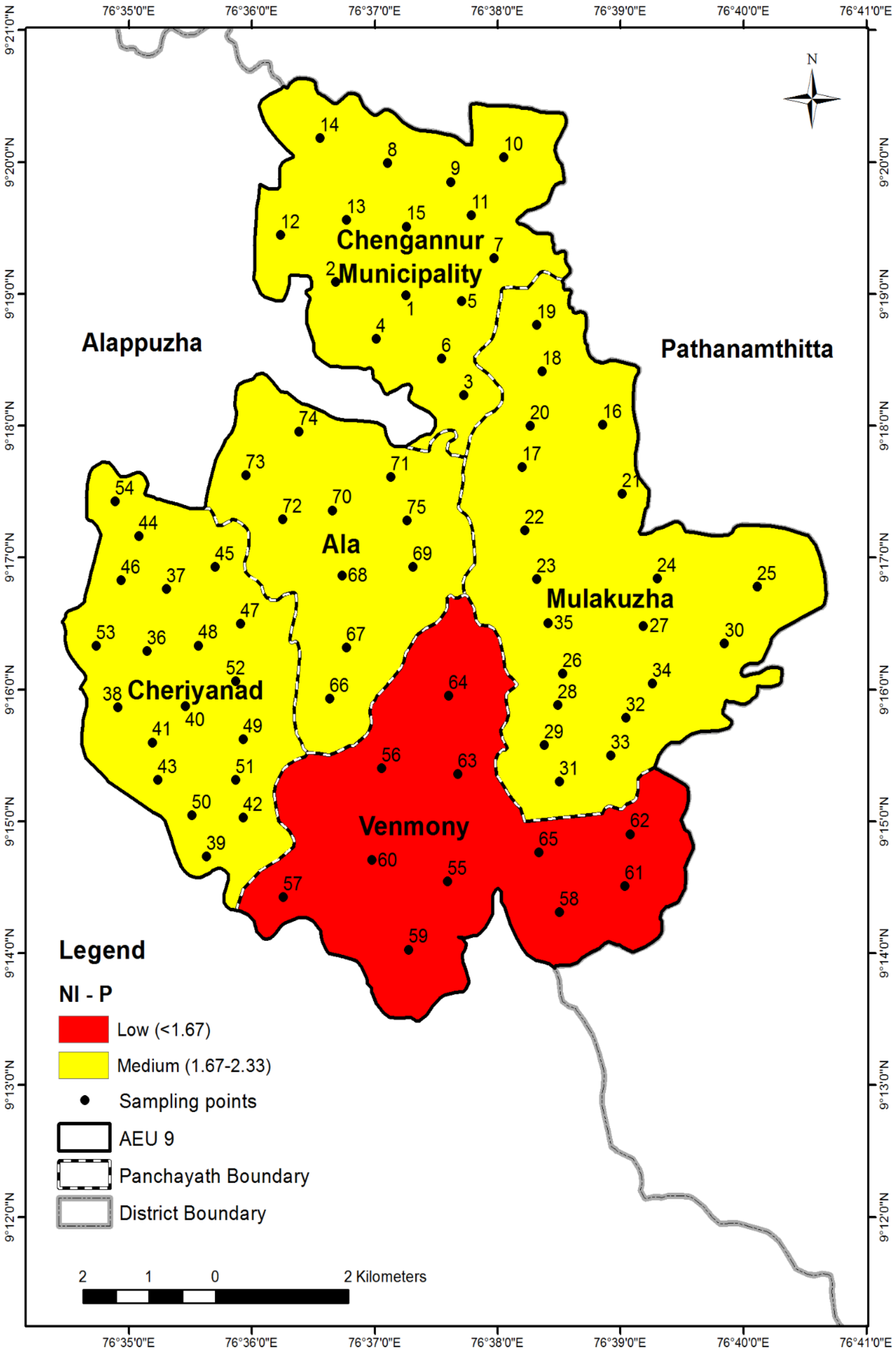


Fig 38. Spatial variability of NI-P in the post-flood soils of AEU 9 in Alappuzha

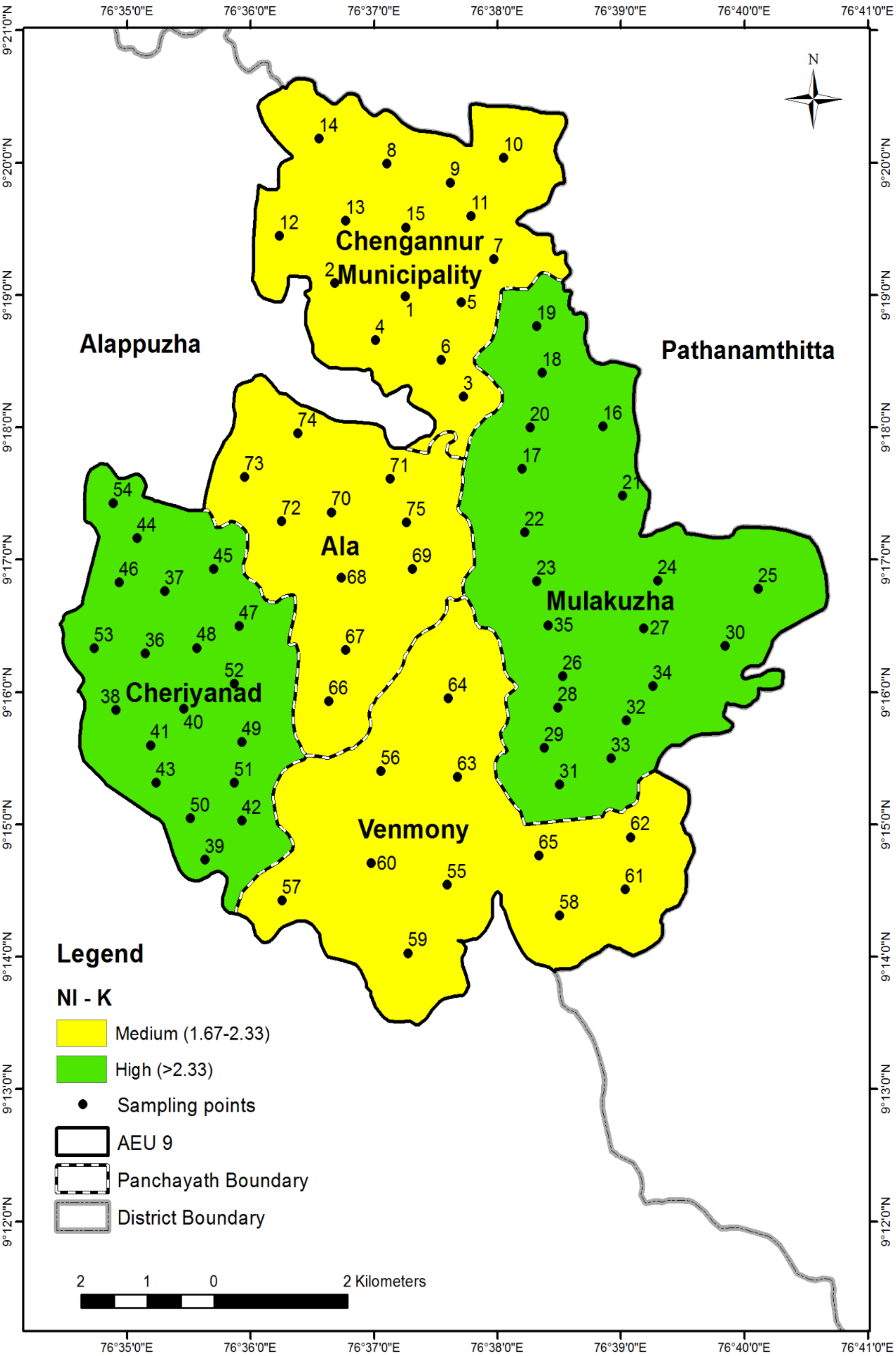


Fig 39. Spatial variability of NI-K in the post-flood soils of AEU 9 in Alappuzha

5.4 LAND QUALITY INDEX

Land quality index was computed based on soil organic carbon stock in kgm^{-2}. LQI was very low (< 3 kgm^{-2}) in 60.1% of soils, low (3-6 kgm^{-2}) in 37.3% and medium (6-9 kgm^{-2}) in 2.6% of soils (Fig 39). Spatial variability of LQI in flood affected soils of AEU 9 is depicted in Fig 40. The soil organic carbon stock varied between 1.02 kg m^{-2} and 7.02 kgm^{-2}. LQI was very low in majority of the areas in Venmony, Ala and Chengannur, whereas it was low in Chengannur, Mulakkuzha and medium in some parts of Chengannur. 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).

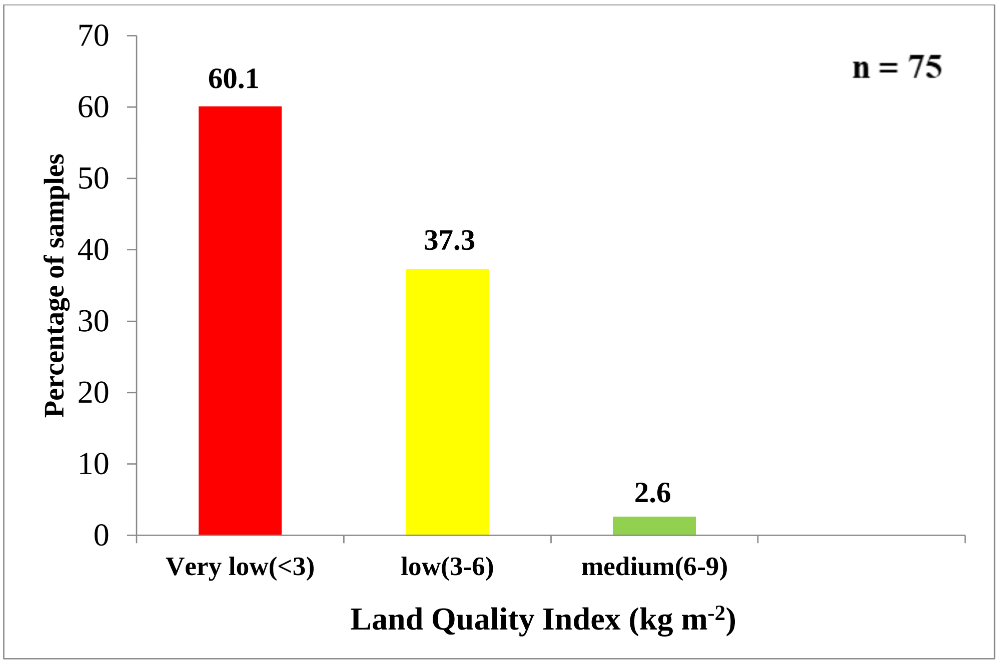
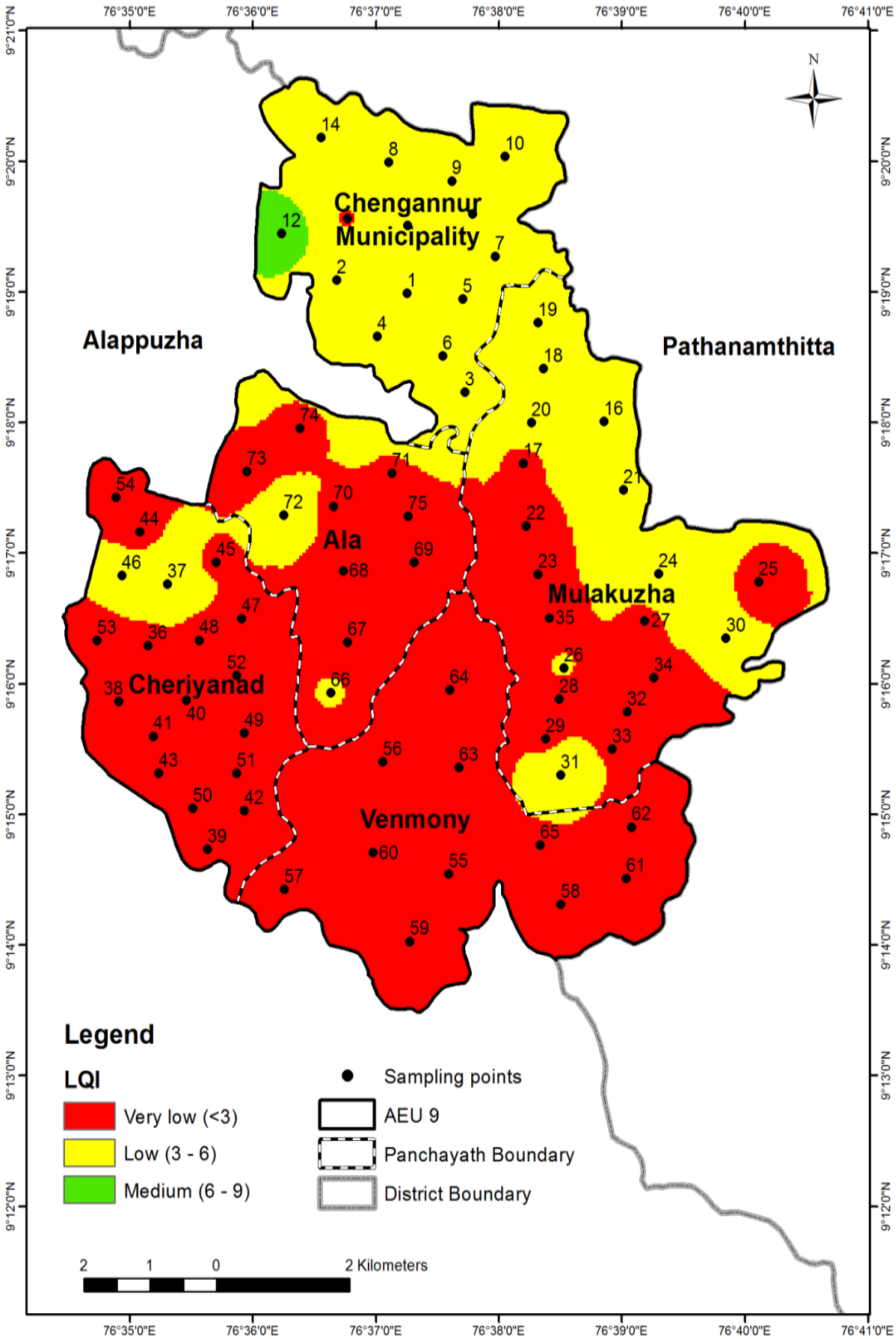


Fig 40. Frequency distribution of LQI (kg m^{-2}) in the post-flood soils of AEU 9 in Alappuzha district



Fg 41. Spatial distribution of LQI in the post-flood soils of AEU 9 in Alappuzha district

5.5. COMPARISON OF PRE AND POST- FLOOD SOILS OF AEU 9

Agro ecological unit - AEU 9 in Alappuzha district was severely affected by the devastating flood which occurred in August, 2018. Chengannur municipality was the worst affected followed by Mulakkuzha, Ala, Cheriyanad and Venmony panchayats. Large quantity of sediment deposition was observed in this area after flooding. In post flood soils a slight shift from sandy clay to sandy loam texture was noticed in surface soil which is attributed to deposition of sediments of sand and silt. It would have contributed to improving the porosity and moisture content of the soil and decreasing the bulk density of soil in some parts of the study area.

Majority of soils were in the extremely acid to strongly acidic category after the flood. An increase in percent of soils with extreme acid pH was observed in post flood soils (20%) compared to pre flood indicating leaching of basic cations from soil which requires liming. Soils with strongly acidic pH increased in post flood soil (30.7%) compared to pre flood (28%) whereas percentage of samples with moderately acidic and slightly acidic pH decreased (Table 26). An increase in organic carbon status of the soil was observed after the flood. Organic carbon status was increased from 18% in pre flood to 38.7% in post flood in high category and from 47% to 61.3% in medium category. This can be attributed to the deposition of sediments rich in organic matter and clay under the inflow of flood water.

The available phosphorus in soil was found to decrease after the flood. There was a sharp decline in the percentage of soils under high category of P after flood from 68% to 26.7%. Available K status in soil increased in post flood soils compared to pre flood values. Only 2.3 % of soils were low in K in post flood compared to 29 % in pre flood.

The available calcium content in soil decreased after the flood and was deficient in 63.9% of soils in post flood compared to 25% in pre flood which is attributed to the leaching of basic cations in flood water. Most of the samples were adequate in sulphur before and after the floods. Boron was deficient in 100 % of the samples. A drastic decline in concentration of available Mg was observed in post flood soils compared to pre flood situation. It was deficient in 100% of post flood soils while 95 % of pre flood soils were in the sufficient range. Available sulphur was adequate while available boron was deficient in all soils before and after the floods.

Table 26. Comparison of parameters of pre and post-flood soils of AEU 9 of Alappuzha district

Parameters	Fertility class	Percent samples	
		Pre flood (KSPB, 2013)	Post flood
pH	Extremely acidic	--	20.0
	Very strongly acidic	34.0	30.7
	Strongly acidic	28.0	30.6
	Moderately acidic	27.0	10.7
	Slightly acidic	11.0	8.0
OC (%)	Low	35.0	--
	Medium	47.0	61.3
	High	18.0	38.7
Available P (kg ha^{-1})	Low	17.0	13.3
	Medium	15.0	60.0
	High	68.0	26.7
Available K (kg ha^{-1})	Low	29.0	2.3
	Medium	46.0	53.1
	High	25.0	44.6
Available Ca (mg kg^{-1})	Deficient	25.0	63.9
	Sufficient	75.0	36.1
Available Mg (mg kg^{-1})	Deficient	5.0	100.0

	Sufficient	95.0	--
Available S (mg kg^{-1})	Deficient	--	6.7
	Sufficient	100.0	93.3
Available B (mg kg^{-1})	Deficient	95.0	100.0
	Sufficient	5.0	--

5.6. SUGGESTED INTERVENTIONS IN AEU 9 OF ALAPPUZHA DISTRICT

Changes in soil properties after flood will directly influence crop production in this region. The major land uses in AEU 9 are coconut, banana, tapioca, vegetables, rubber and paddy. For successful crop production it is necessary to bring changes in nutrient management practises according to the status of soil after the flood.

During the period of flood, sediment deposition occurred on most of the cultivated lands near river banks particularly in Chengannur, Cheriyanad and Venmony panchayaths. The sediment materials deposited on crop lands constituted mainly of sand fractions which have to be removed wherever possible to make the land suitable for future cultivation. Management of soil acidity is important as the pH of the soil decreased after the flood. Liming of these soils based on soil test results is highly essential. Application of lime 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, making organic manures application important.

Available nitrogen content in flood affected soils are low 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 medium and high respectively, so application of phosphorus and potassium fertilizers can be reduced based on the current soil status. Magnesium and boron are deficient in this area. 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 Alappuzha 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 Alappuzha district, to develop maps on soil characters and quality using GIS techniques and to work out the Soil Quality Index (SQI).

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.* Mulakuzha, Ala, Cheriyanad, Venmony and Chengannur municipality.

The 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, organic carbon, available N, P, K, Ca, Mg, S and B) and biological (acid phosphatase and dehydrogenase activity) parameters for evaluating soil quality. GIS based thematic maps of soil characters and quality were prepared.

A minimum data set (MDS) of indicators for assessing soil quality was set up using principal component analysis (PCA). Twenty two 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, organic carbon, available N, P, K, Ca, Mg, S, B, acid phosphatase and dehydrogenase activity) were analysed using PCA and a MDS of eight parameters (clay, available N, P, K, Ca, S, bulk density and EC) yielded from seven principal components(PC1 to PC 7) 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 entire area of AEU 9 in Alappuzha district was affected by flood. Chengannur Municipality was the worst affected followed by Mulakkuzha, Ala, Cheriyanad and Venmony panchayaths.
- Coconut was the major crop cultivated by majority of farmers (60.1%) followed by banana (9.31%) and vegetables (9.23%). Crops such as banana, nutmeg, tuber crops, paddy and vegetables were severely damaged by the impounding of water for a week and severe crop loss was reported.
- Integrated nutrient management (INM) practices were followed by 70.6% farmers followed by organic (17.3%) and conventional (12.1%) practices. Most of the farm holdings were < 2 ha in size (72.1%).
- Sediment deposition of sand, silt and clay to a depth of 0-15 cm were observed in Chengannur, Cheriyanad and Venmony.
- The highest bulk density of 1.6 Mg m^{-3} and porosity of 71.6% were observed in Venmony whereas particle density was the highest in Mulakuzha (2.2 Mg m^{-3}).
- Sandy loam was the predominant soil texture observed in 58.6% of the flood affected soils of AEU 9 followed by silty clay and sandy clay texture in 13.3% soils.
- The soil moisture content varied between 11.3 and 24.4% with the highest content in Cheriyanad and lowest in Venmony. The highest water holding capacity of 55.1% was recorded in Chengannur and lowest of 39.3% in Venmony.
- Venmony showed the highest MWD (0.76mm) and lowest WSA (46.34%) whereas Chengannur showed lowest MWD (0.52mm) and highest WSA (55.61%).
- Majority of soils had bulk density between 1.4 and 1.6 Mg m^{-3} (50.7%), particle density < 2.2 Mg m^{-3} (57.3%), porosity between 50-70% (66.7%), maximum

water holding capacity <30% (70%), soil moisture content between 15-25 percent (80.1%), MWD <1mm (78.7%) and WSA <30 percent (57.33%).

- Soil pH varied between 4.10 and 6.90 with a mean value of 5.02. About 30.7% of the soils were very strongly acidic (4.5-5.5), 30.6% strongly acidic (5.0-5.5) and 20% extremely acidic (3.5-4.5). Electrical conductivity was less than 1 dSm^{-1} in all the soils. Majority (75 percent) of the soils had exchangeable acidity between 1.0-2.0 $meq100g^{-1}$
- The organic carbon content was the highest in Chengannur (2.41%) followed by Mulakuzha (1.61%) and the lowest in Ala (0.81%). Organic carbon was rated medium for 61.3% and high for 38.7% of the soils.
- Mulakuzha recorded the highest mean value of available N (233 kg ha^{-1}), P (4.2 kg ha^{-1}) and K (29.9 kg ha^{-1}). Majority (89.3%) of the soils were low in available N status. About 60% of the soils were rated medium for available P and 53.1% soils were medium in available K content.
- Chengannur recorded the highest mean value for available calcium (327 mg kg^{-1}) and available boron (0.31 mg kg^{-1}). Venmony registered the highest mean of available magnesium (129 mg kg^{-1}) and available sulphur (17.91mg kg^{-1}). Calcium (63.9%), magnesium (100%) and boron (100%) were deficient and sulphur (93.3%) was sufficient in majority of soils.
- Majority (76%) of soils had 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 64% of the soils.
- Relative soil quality index ranged from 32.5 to 62.5% with a mean value of 43.6%. Soil quality was observed to be higher in Mulakuzha which had also registered relatively higher available N, P, K and organic carbon. About 80% of soils were rated poor and 20% were medium in soil quality.
- Nutrient index of the study area in terms of organic carbon and nitrogen were medium and low respectively for all the panchayats. The nutrient index for phosphorous was medium in all the panchayats except Venmony (low). Nutrient index for potassium was high in Mulakuzha and Cheriyanad and medium in Chengannur, Venmony and Ala.

- Soil organic carbon stock ranged between 1.02 and 7.02 Kg m^{-2} in the study area. The highest value was observed in Chengannur (6.76 Mg m^{-2}) where high organic carbon was observed. LQI was very low (<3 Kg m^{-2}) in 60.1%, low (3-6 Kg m^{-2}) in 37.3% and medium (6-9 Kg m^{-2}) in 2.6% of the soils.

Comparison with pre flood data of KSPB (2013) showed an increase in percent of soils with extremely acid pH from 0 to 20% due to flooding which indicated leaching of basic cations from soil. Soil pH was extremely acidic in some areas of Cheriyanad, Ala, Venmony and Mulakuzha panchayats. Organic carbon status increased after the floods from 18 to 38.7% and from 47 to 61.3% in the high and medium categories respectively. Percent of soils with medium level of available P, high level of available K, deficient levels of available Ca, Mg and B was higher after the flood whereas soils adequate in available sulphur and high levels of available P declined.

From the study it is concluded that soil condition and nutrient status were slightly altered in the soils of AEU 9 in Alappuzha district after the 2018 flood. Soil acidity increased in some areas due to the leaching of basic cations and erosion by flowing flood water. This is evident from the deficient levels of calcium and magnesium observed after the flood. Organic carbon status, available K and S were increased and available P slightly decreased after the floods in the areas with sediment deposits.

Soil quality was found to be higher in Chengannur and Mulakuzha where sediment deposits of clay and silt were observed. 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 ALAPPUZHA 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 of Alappuzha district in 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 Alappuzha district, to work out the soil quality index and to generate maps of various soil attributes and quality using GIS techniques.

Survey conducted to identify the flood affected areas in AEU 9 of Alappuzha district revealed that the entire area of AEU 9 in Alappuzha district was affected by flood. Chengannur municipality was the worst affected followed by Mulakkuzha, Ala, Cheriyanad and Venmony panchayaths. About 75% of the study area was under coconut based cropping system with marginal farmers (72.1%) practicing integrated nutrient management (70.6%).

Geo referenced surface soil samples (0-20 cm) were collected from seventy five sites from the five flood affected panchayaths and characterized for various physical, chemical and biological attributes. Minimum data set of soil indicators for computing soil quality were selected using principal component analysis. The selected parameters were clay per cent, bulk density, electrical conductivity, available N, available P, available K, available Ca, and available S. Scores and weights were assigned to each selected indicator, and were aggregated and soil quality index was computed. GIS techniques were used to generate thematic maps of various soil attributes and soil quality indices.

The dominant textural class was sandy loam. The particle density and bulk density of soil ranged from 2.10 to 2.60 and 1.10 to 1.80 Mgm^{-3} respectively. Majority (66.7%) of the soils had porosity in the range of 50 to 70%. The soil moisture content ranged between 11.33 to 24.44%. The water holding capacity and water stable aggregates ranged from 32.12 to 74.63% and 37.3 to 70.6% respectively. Deposition of sediments was observed in all the panchayaths with maximum deposition of 10 to 15cm thickness in Chengannur, Cheriyanad and Vemony. There was an increase in soil acidity after floods and 20% of the soils became extremely acidic (3.5-4.5). The electrical conductivity of soil ranged between 0.10 to 0.60 dSm^{-1}. An increase in

organic carbon status was observed post flood with 38.7 % of soils having high organic carbon content compared to 18 % before the floods. The available nitrogen in soil ranged between 100 and 627 kg ha^{-1} with 89.3 % of soils in low category. A decrease in available phosphorous, calcium and magnesium was observed in the post flood soils. Available P was low in 13.3 % of soils and 64 % of soils were deficient in calcium while all the soils were deficient in magnesium and boron. Available K was medium to high (100 to 492 kg ha^{-1}) in most of the soils. Majority (93.3%) of the soils showed adequate sulphur (> 5 mg kg^{-1}) before and after the floods.

The relative soil quality index ranged from 32.5 to 62.5%. Majority (80%) of the soils had low soil quality index and the remaining had medium soil quality index. Mulakuzha panchayath recorded the highest soil quality index followed by Chenganuur while Venmony showed the lowest. With regard to land quality index, 60.1 % of soils fall under very low category while 37.33 % under low category. Chengannur municipality recorded the highest LQI followed by Mulakuzha panchayath while Venmony recorded the lowest. Nutrient index for organic carbon and nitrogen were medium and low in all panchayats. Nutrient index for phosphorous was low in Venmony panchayath while it was medium in all other panchayaths. Nutrient index for potassium was high in Ala and Mulakuzha panchayaths and medium in other panchayats.

The results of the study reveal strongly acidic to extremely acidic soils in majority of the flood affected areas of AEU 9. Organic carbon, available phosphorous, potassium and sulphur levels increased while widespread deficiency of nitrogen and calcium were observed in majority of the panchayats. The entire study area showed deficiency of magnesium and boron. The results outline the need for regular liming to control soil acidity and to alleviate calcium deficiency. The soils should be supplemented with nitrogen, magnesium and boron to improve soil quality and to sustain productivity.

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
Chengannur	1.	10 cent	Coconut	Conventional
	2.	30 cent	Banana	INM
	3.	1 ha	Nutmeg	INM
	4.	50 cent	Coconut	INM
	5.	30 cent	Coconut	INM
	6.	2 ha	Coconut	INM
	7.	25 cent	Coconut	INM
	8.	10 cent	Tapioca	INM
	9.	1 ha	Coconut	INM
	10	20cent	Coconut	INM
	11	40cent	Coconut	Conventional
	12	1 ha	Paddy	INM
	13	10cent	Vegetables	Organic
	14	1 ha	Nutmeg	Conventional
	15	1.6 ha	Coconut	INM
Mulakuzha	16	10 cent	Vegetables	Organic
	17	20 cent	Vegetables	Organic
	18	20 cent	Tapioca	Conventional
	19	40 cent	Coconut	INM
	20	1 ha	Nutmeg	INM
	21	1 ha	Coconut	INM
	22	20 cent	Coconut	INM
	23	15 cent	Tapioca, yams	Organic
	24.	20 cent	vegetables	Organic
	25.	1 ha	Coconut	INM
	26.	15 cent	Coconut	Conventional
	27.	1 ha	Coconut	INM
	28.	30 cents	Coconut	Conventional
	29.	25 cent	Coconut	Conventional
	30.	1 ha	Nutmeg	INM
	31.	1 ha	Coconut	INM
	32.	10 cent	Coconut	Organic
	33.	1 ha	Coconut	INM
	34	1 ha	Paddy	INM
	35	10 cent	Banana	INM
Cheriyanad	36.	10 cent	Vegetables	Organic
	37.	25 cent	Banana	INM
	38.	20 cent	Tapioca	INM
	39.	20 cent	Coconut and banana	INM
	40.	35 cent	banana, tapioca	Conventional
	41.	1 ha	Nutmeg	Conventional
	42.	20 cent	Banana and Tapioca	Organic
	43.	1 ha	Nutmeg	INM

Panchayath/ Muncipality	Sample No.	Size of holding	Crops	Nutrient management
	44.	50 cents	Coconut	INM
	45.	20 cent	Banana	INM
	46.	35 cent	Coconut	INM
	47.	1 ha	Banana, coconut, arecanut, and Nutmeg	INM
	48.	30 cent	Banana and tapioca Vegetables	INM
	49.	35 cent	Arecanut, banana, coconut and vegetables	INM
	50.	30 cent	Tapioca and Vegetables	Organic
	51.	15 cent	Banana	INM
	52.	35 cent	Vegetables, banana and tapioca	INM
	53.	1 ha	Paddy, coconut, banana	INM
	54.	35 cent	Banana and tapioca Vegetables	Organic
	55.	25 cent	Banana, tapioca and Vegetables	INM
Venmony	56.		Tapioca and vegetables	INM
	49.	25 cent	Tapioca and vegetables	Organic
	50.	30 cent	Tapioca and vegetables	INM
	51.	25 cent	Banana	INM
	52.	30 cent	Vegetables	INM
	53.	10 cent	Tapioca	INM
	54.	50 cent	Pepper, coconut, Nutmeg and tapioca	INM
	55.	20 cent	Banana	INM
	56.	10 cent	Tapioca	INM
	57.	20 cent	Tapioca	INM
	58.	1 ha	Banana, coconut, nutmeg	INM
	59.	10 cent	Tapioca	INM
	60.	1.5 ha	Coconut, nutmeg	INM
	61.	10 cent	Elephant foot yam and taro	INM
	62.	30 cent	Cashew, Banana	INM
	63.	1 ha	Coconut, cashew, Nutmeg	INM
	64.	1 ha	Banana and coconut	INM
	65.	20 cent	Coconut	INM
Ala	66.	20 cent	Banana and tapioca	INM
	67.	1 ha	Coconut	INM
	68.	20 cent	Banana	INM
	69.	1 ha	Coconut	INM
	70.	25 cent	Banana	INM
	71.	1 ha	Coconut	INM
	72.	25 cent	Banana	INM
	73.	10 cent	Vegetables	Organic
	74.	20 cent	Banana	INM
	75.	20 cent	Tapioca, Vegetables, yams, banana	Organic

Appendix III
ANALYSIS RESULTS
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
Chengannur Municipality											
1	2.3	1.6	69.4	34.5	55.8	0.4	47.2	11.3	50.2	56.3	silty clay
2	2.1	1.2	55.8	36.7	55.0	0.3	44.8	10.5	46.6	50.5	silty clay
3	2.4	1.1	47.6	47.7	57.3	0.4	44.5	9.9	43.3	52.6	silty clay
4	2.1	1.4	69.6	45.5	50.9	0.8	65.7	39.5	32.1	60.7	clay
5	2.1	1.3	64.8	41.3	55.9	0.7	70.1	50.7	11.2	40.3	sandy clay
6	2.1	1.1	54.7	41.2	74.6	0.6	70.4	38.9	27.8	70.9	clay
7	2.6	1.1	44.1	39.9	56.3	0.3	44.4	15.8	57.8	35.5	silty clay
8	2.6	1.4	53.2	42.1	51.5	0.6	70.3	9.9	50.7	50.8	silty clay
9	2.3	1.6	73.0	47.8	50.9	0.6	63.9	15.5	47.7	49.8	silty clay
10	2.4	1.5	62.3	22.3	50.2	0.8	65.1	50.7	11.9	40.9	sandy clay
11	2.1	1.3	62.9	44.4	53.1	0.5	52.8	17.8	45.4	58.4	silty clay
12	2.1	1.2	58.1	40.1	52.3	0.4	49.5	14.6	49.8	59.7	silty clay
13	2.4	1.3	55.7	22.1	55.2	0.3	48.2	49.8	12.7	39.9	sandy clay
14	2.3	1.4	61.0	44.1	52.3	0.4	46.8	18.4	52.3	47.8	silty clay
15	2.1	1.4	68.2	49.8	55.4	0.8	50.3	39.8	30.7	78.9	clay
Mulakuzha											
16	2.1	1.1	53.4	59.6	67.3	0.5	67.0	39.4	37.7	80.2	clay
17	2.6	1.3	50.5	43.5	47.6	0.7	70.6	50.8	47.2	12.3	sandy loam
18	2.2	1.2	53.0	47.8	49.3	0.5	40.0	47.8	35.7	10.9	sandy loam
19	2.6	1.4	56.5	41.1	41.6	0.4	40.4	60.4	46.1	9.8	sandy loam
20	2.1	1.2	59.6	46.7	41.6	0.9	61.2	78.3	37.3	7.6	sandy loam
21	2.4	1.6	68.2	41.5	44.8	0.4	44.1	72.8	24.1	6.9	sandy loam
22	2.3	1.4	61.9	48.9	33.8	0.8	52.8	39.8	56.7	20.8	silty loam
23	2.1	1.6	78.1	41.2	52.9	0.5	49.5	63.9	30.9	11.2	sandy loam
24	2.1	1.4	65.3	48.9	55.0	0.4	51.2	70.2	35.9	13.2	sandy loam
25	2.4	1.4	61.0	52.3	69.8	0.5	44.8	38.4	23.3	70.6	clay
26	2.1	1.6	74.5	42.2	49.3	0.3	54.4	74.1	45.8	15.1	sandy loam

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
27	2.4	1.4	58.5	39.8	41.6	0.9	47.4	49.8	48.1	9.8	sandy loam
28	2.1	1.6	78.1	42.2	44.8	0.9	42.1	34.4	50.2	19.8	silty loam
29	2.1	1.4	69.1	37.8	33.8	1.0	49.3	69.8	29.8	7.6	sandy loam
30	2.1	1.3	62.4	36.4	52.9	1.0	57.7	76.8	39.4	6.6	sandy loam
31	2.1	1.4	66.7	37.6	55.0	0.4	48.9	79.9	43.3	8.3	sandy loam
32	2.4	1.2	49.3	52.2	69.8	0.2	51.3	34.3	39.9	79.9	clay
33	2.1	1.3	63.4	48.9	61.9	0.6	37.3	30.9	38.8	76.5	clay
34	2.2	1.1	51.0	37.9	52.3	1.0	51.4	69.9	34.2	8.9	sandy loam
35	2.3	1.3	57.5	39.9	62.3	0.6	55.2	29.8	29.8	70.1	clay
Cheriyanad											
36	2.1	1.1	53.4	59.6	67.3	0.5	67.0	39.4	37.7	80.2	clay
37	2.6	1.3	50.5	43.5	47.6	0.7	70.6	50.8	47.2	12.3	sandy loam
38	2.2	1.2	53.0	47.8	49.3	0.5	40.0	47.8	35.7	10.9	sandy loam
39	2.6	1.4	56.5	41.1	41.6	0.4	40.4	60.4	46.1	9.8	sandy loam
40	2.1	1.2	59.6	46.7	41.6	0.9	61.2	78.3	37.3	7.6	sandy loam
41	2.4	1.6	68.2	41.5	44.8	0.4	44.1	72.8	24.1	6.9	sandy loam
42	2.3	1.4	61.9	48.9	33.8	0.8	52.8	39.8	56.7	20.8	silty loam
43	2.1	1.6	78.1	41.2	52.9	0.5	49.5	63.9	30.9	11.2	sandy loam
44	2.1	1.4	65.3	48.9	55.0	0.4	51.2	70.2	35.9	13.2	sandy loam
45	2.4	1.4	61.0	52.3	69.8	0.5	44.8	38.4	23.3	70.6	clay
46	2.1	1.6	74.5	42.2	49.3	0.3	54.4	74.1	45.8	15.1	sandy loam
47	2.4	1.4	58.5	39.8	41.6	0.9	47.4	49.8	48.1	9.8	sandy loam
48	2.1	1.6	78.1	42.2	44.8	0.9	42.1	34.4	50.2	19.8	silty loam
49	2.1	1.4	69.1	37.8	33.8	1.0	49.3	69.8	29.8	7.6	sandy loam
50	2.1	1.3	62.4	36.4	52.9	1.0	57.7	76.8	39.4	6.6	sandy loam
51	2.1	1.4	66.7	37.6	55.0	0.4	48.9	79.9	43.3	8.3	sandy loam
52	2.4	1.2	49.3	52.2	69.8	0.2	51.3	34.3	39.9	79.9	clay
53	2.1	1.3	63.4	48.9	61.9	0.6	37.3	30.9	38.8	76.5	clay
54	2.2	1.1	51.0	37.9	52.3	1.0	51.4	69.9	34.2	8.9	sandy loam
55	2.3	1.3	57.5	39.9	62.3	0.6	55.2	29.8	29.8	70.1	clay

Sl. No.	Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	Moisture Content (%)	WHC (%)	MWD (mm)	WSA (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Venmony											
56	2.1	1.2	58.1	41.8	50.2	0.7	50.3	50.1	11.2	40.6	sandy clay
57	2.1	1.6	73.2	33.2	44.2	0.9	47.4	50.6	30.2	11.2	sandy loam
58	2.3	1.6	71.4	27.6	47.9	0.9	42.1	46.7	23.5	9.8	sandy loam
59	2.3	1.7	72.2	34.3	45.8	0.6	55.2	51.2	41.1	6.4	sandy loam
60	2.3	1.7	75.3	26.7	22.6	0.7	49.9	78.9	33.5	5.9	sandy loam
61	2.3	1.7	75.8	24.6	32.2	0.4	46.0	66.4	36.5	7.8	sandy loam
62	2.1	1.6	73.5	28.4	35.7	0.6	45.4	65.4	29.8	8.4	sandy loam
63	2.3	1.7	74.0	34.4	33.3	0.5	45.8	54.2	24.9	12.4	sandy loam
64	2.2	1.7	76.9	36.6	44.4	0.3	30.3	58.8	28.9	14.7	sandy loam
64	2.3	1.5	66.2	34.5	42.2	0.9	47.4	47.8	45.8	9.5	sandy loam
65	2.3	1.6	70.6	38.9	33.2	0.9	46.1	78.6	40.8	8.2	sandy loam
Ala											
66	2.1	1.6	71.3	56.4	54.4	1.0	59.3	50.2	11.5	40.6	sandy clay
67	2.2	1.3	60.1	31.3	46.6	0.8	47.7	45.6	35.7	11.9	sandy loam
68	2.2	1.4	64.6	39.3	32.1	0.9	42.1	44.8	38.9	9.8	sandy loam
69	2.2	1.5	69.2	47.2	39.0	0.7	49.3	53.3	19.8	25.6	sandy clay loam
70	2.1	1.6	69.5	39.6	40.9	1.0	47.7	78.6	46.7	14.8	sandy loam
71	2.3	1.4	61.9	53.2	57.9	0.4	48.9	46.7	13.2	38.9	sandy clay
72	2.2	1.3	61.5	56.7	49.7	0.8	52.0	54.8	15.4	41.1	sandy clay
73	2.3	1.2	53.2	31.2	48.0	0.6	37.3	72.6	43.8	7.8	sandy loam
74	2.1	1.6	76.8	54.6	55.9	0.7	51.4	33.8	49.7	32.9	clay loam
75	2.3	1.4	61.3	39.3	43.3	0.6	44.8	78.9	32.8	9.8	sandy loam

Appendix III
ANALYSIS RESULTS
Soil chemical and biological parameters

Sl. No.	pH	Ex. Acidity (cmolg⁻¹)	EC (dSm⁻¹)	OC %	N_2 (kgha⁻¹)	P (kgha⁻¹)	K (kgha⁻¹)	Ca (mgkg⁻¹)	Mg (mgkg⁻¹)	S (mgkg⁻¹)	B (mgkg⁻¹)	acid phosphatase (µg PNP produced g soil⁻¹h⁻¹)	Dehydrogenase (µg PNP produced g soil⁻¹h⁻¹)
Chengannur municipality													
1	5.0	1.3	0.2	2.3	112.9	14.5	212.8	349.3	54.5	6.5	0.6	17.7	17.0
2	6.1	1.4	0.1	3.2	150.5	16.4	201.6	110.2	50.6	7.0	0.2	36.4	25.2
3	7.6	1.3	0.1	2.5	187.8	10.6	112.0	407.7	59.3	5.5	0.6	25.2	25.1
4	5.0	2.3	0.1	2.4	163.1	9.3	189.6	427.4	61.3	5.5	0.6	27.8	25.3
5	5.2	1.3	0.1	2.7	150.5	23.9	246.4	322.5	109.0	7.5	0.0	36.0	25.2
6	5.5	2.1	0.1	2.2	100.4	44.6	145.6	478.4	59.9	4.0	0.2	28.9	24.6
7	5.0	1.3	0.3	2.1	138.0	16.0	178.4	464.8	57.7	6.5	0.0	36.2	25.2
8	5.2	2.3	0.1	2.4	125.4	23.1	212.8	473.7	54.0	6.5	0.0	36.1	25.4
9	5.1	2.1	0.4	2.3	100.4	9.3	190.4	183.0	50.4	4.5	0.2	36.2	25.7
10	5.2	2.3	0.1	2.4	150.5	16.3	178.4	272.9	58.5	10.0	0.1	32.2	17.5
11	4.8	2.3	0.1	1.6	175.6	9.9	156.0	112.9	60.1	6.0	0.2	26.4	17.8
12	5.1	1.3	0.1	3.9	225.8	10.0	100.8	184.2	76.8	3.0	0.4	36.5	25.4
13	4.5	2.2	0.2	1.6	263.4	9.5	134.4	435.6	106.8	4.0	0.3	18.8	17.8
14	6.1	2.0	0.1	2.5	138.0	11.3	189.6	273.6	52.0	6.0	0.3	36.7	17.9
15	5.6	1.4	0.1	2.3	163.1	17.7	212.8	415.0	56.8	3.0	0.1	18.9	17.6
Mulakkuzha													
16	5.6	1.0	0.2	2.2	200.7	28.4	268.8	324.0	59.7	16.5	0.1	34.5	17.9
17	5.6	1.1	0.2	1.3	100.6	28.7	302.4	365.3	59.1	19.5	0.0	21.1	26.1
18	4.6	2.4	0.1	1.5	238.3	9.4	123.2	301.5	85.0	10.0	0.0	32.7	26.2
19	5.0	2.1	0.1	2.0	627.2	22.8	112.0	342.3	61.4	10.0	0.0	33.5	18.8
20	4.7	2.6	0.1	1.4	363.8	12.1	168.0	302.9	54.0	5.5	0.2	22.1	26.2
21	4.2	1.4	0.1	1.1	225.8	38.6	428.0	314.2	59.2	10.0	0.2	31.5	26.5
22	5.6	2.5	0.1	1.6	125.4	9.9	212.8	354.1	89.8	11.5	0.1	23.1	26.9
23	5.2	2.5	0.4	1.3	150.5	9.6	436.8	177.3	91.7	12.0	0.0	30.5	25.4
24	5.5	1.6	0.1	2.4	238.3	18.3	268.8	118.8	80.0	11.0	0.0	24.1	25.3
25	5.2	2.4	0.4	1.8	313.6	25.3	246.4	110.1	99.4	11.5	0.0	31.5	18.1

Sl. No.	pH	Ex. Acidity (cmolg1)	EC (dSm-1)	OC %	N_2 (kgha-1)	P (kgha-1)	K (kgha-1)	Ca (mgkg-1)	Mg (mgkg-1)	S (mgkg-1)	B (mgkg-1)	acid phosphatase (µg PNP produced g soil-1h-1)	Dehydrogenase (µg PNP produced g soil-1h-1)
26	4.6	1.8	0.3	1.3	125.1	11.0	268.8	117.4	78.6	15.0	0.01	31.5	17.8
27	4.9	1.9	0.1	1.2	175.6	8.3	224.0	211.2	94.2	6.0	0.01	25.8	26.8
28	4.7	1.4	0.1	1.9	288.5	18.5	347.2	378.4	59.9	11.0	0.2	21.1	25.9
29	4.8	2.6	0.3	1.2	137.6	47.8	415.2	364.8	57.7	15.5	0.2	22.1	18.8
30	4.6	1.5	0.3	1.6	213.2	9.8	492.8	373.7	59.0	15.5	0.1	33.5	20.1
31	4.5	2.5	0.3	2.1	313.6	39.5	369.6	183.0	50.4	8.5	0.1	23.5	26.9
32	5.3	1.6	0.1	1.2	213.2	14.1	403.2	172.9	58.5	11.5	0.01	32.5	25.7
33	4.6	2.5	0.1	1.5	263.4	9.5	324.8	194.9	60.1	5.5	0.01	25.6	18.9
34	4.5	2.4	0.1	1.8	200.7	10.3	134.4	184.2	76.8	6.0	0.01	34.5	19.9
35	4.2	2.6	0.2	1.3	150.5	11.9	437.6	302.9	54.0	15.0	0.1	28.7	19.9
Cheriyanad													
36	4.9	1.3	0.2	0.6	213.2	9.5	336.0	274.2	106.0	22.5	0.01	33.8	25.4
37	4.0	1.7	0.1	2.6	187.8	16.8	436.8	127.5	58.9	5.5	0.2	32.7	25.0
38	4.9	1.2	0.2	0.6	138.0	25.3	405.6	172.6	52.1	17.0	0.01	31.5	25.3
39	4.6	1.4	0.6	1.3	163.1	9.5	179.2	265.4	50.4	23.5	0.1	30.9	25.1
40	5.6	2.6	0.1	0.7	137.6	23.1	302.4	168.7	57.2	23.0	0.1	19.0	25.5
41	4.2	1.3	0.2	1.0	225.8	8.0	190.4	316.8	50.3	15.5	0.5	33.3	25.4
42	4.2	1.5	0.1	1.3	200.7	9.4	123.2	275.3	50.5	4.5	0.01	31.6	25.0
43	5.5	1.4	0.2	0.8	125.4	8.6	190.4	277.5	54.5	5.5	0.01	32.1	13.1
44	4.7	2.1	0.1	0.8	112.9	9.0	302.4	170.9	56.9	5.0	0.1	30.8	13.2
45	5.3	1.8	0.1	1.0	175.6	9.0	190.4	121.2	130.9	7.5	0.01	30.9	25.1
46	5.0	1.6	0.4	1.3	526.8	9.0	268.8	321.6	84.5	5.0	0.1	30.5	25.0
47	5.5	1.4	0.1	0.9	200.7	15.3	460.0	110.8	58.9	6.0	0.01	20.5	13.3
48	4.1	1.5	0.3	0.6	150.5	9.8	336.0	114.5	79.9	12.0	0.01	30.1	25.4
49	5.1	2.4	0.1	1.0	150.5	12.5	380.8	142.8	81.1	7.0	0.01	32.3	25.3
50	4.7	2.1	0.1	0.7	175.3	10.8	257.6	114.2	59.2	8.0	0.1	30.4	25.2
51	4.1	2.0	0.2	0.8	112.9	29.8	123.2	154.1	89.8	7.5	0.2	30.2	25.3
52	6.1	1.8	0.2	0.5	187.8	9.1	168.0	177.3	91.7	11.5	0.1	32.2	25.1
53	4.5	1.4	0.2	0.9	125.4	12.1	280.0	118.8	80.0	7.5	0.0	31.1	25.4
54	4.9	2.6	0.1	0.6	175.6	12.8	392.8	168.7	57.2	5.0	0.1	30.5	25.2

Sl. No.	pH	Ex. Acidity (cmolg^{-1})	EC (dSm^{-1})	OC %	N_2 (kgha^{-1})	P (kgha^{-1})	K (kgha^{-1})	Ca (mgkg^{-1})	Mg (mgkg^{-1})	S (mgkg^{-1})	B (mg kg^{-1})	acid phosphatase (µg PNP produced g soil^{-1}h^{-1})	Dehydrogenase (µg PNP produced g soil^{-1}h^{-1})
Venmony													
55	6.6	1.0	0.1	0.9	188.2	9.1	189.6	160.7	87.1	6.0	0.1	16.0	13.1
56	4.4	1.2	0.1	0.5	150.5	9.7	134.4	179.6	137.4	5.5	0.3	28.6	25.8
57	4.4	2.2	0.1	0.7	200.7	9.3	112.0	175.7	132.4	17.5	0.2	25.4	25.1
58	6.1	2.3	0.1	0.8	213.2	9.5	178.4	162.2	131.1	16.0	0.2	26.2	25.9
59	5.3	1.2	0.1	0.6	138.0	9.1	291.2	374.2	85.0	23.0	0.2	25.2	26.3
60	4.9	1.8	0.1	0.7	188.2	9.6	145.6	162.7	88.7	6.5	0.0	28.9	25.6
61	4.5	1.3	0.1	0.9	238.3	11.2	224.0	146.1	176.3	22.0	0.3	29.5	26.5
62	5.7	1.2	0.1	0.8	200.7	14.7	380.8	123.7	81.0	26.0	0.5	28.8	26.4
63	4.6	2.2	0.1	0.7	225.8	9.3	235.2	304.8	192.8	25.0	0.1	25.2	26.7
64	5.2	1.4	0.1	0.8	188.2	9.1	201.6	163.6	225.9	24.0	0.1	25.6	26.7
65	5.3	1.3	0.2	1.2	150.5	9.4	316.0	129.4	90.0	25.5	0.1	25.7	26.8
Ala													
66	4.3	2.0	0.1	1.3	363.8	9.8	336.0	348.1	92.0	11.5	0.0	18.4	17.9
67	4.8	2.1	0.1	1.1	326.1	9.4	436.8	112.1	67.6	6.0	0.1	34.4	18.9
68	5.1	2.0	0.1	0.7	163.1	11.3	369.6	168.7	47.2	20.0	0.0	18.7	25.5
69	5.3	3.0	0.1	0.8	175.6	9.2	201.6	316.8	50.3	6.5	0.1	36.5	23.4
70	5.3	2.3	0.1	0.8	188.2	15.6	123.2	275.3	50.5	6.0	0.2	15.5	26.2
71	5.4	3,0	0.1	0.6	225.8	10.9	235.2	377.5	54.5	6.5	0.1	37.8	26.4
72	5.5	3.0	0.1	0.5	175.6	10.0	268.8	170.9	46.9	27.5	0.0	30.8	27.3
73	5.6	2.3	0.1	0.9	188.2	28.0	168.0	121.2	80.9	5.0	0.1	29.8	24.5
74	5.0	2.2	0.1	0.6	175.6	9.0	145.6	135.8	54.5	5.5	0.0	18.9	22.5
75	4.7	2.2	0.1	1.1	213.2	9.6	257.6	187.6	53.0	7.5	0.1	18.9	25.1

SQI and LQI

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Chengannur	1	180	45.0	53.4	5.34
	2	175	43.8	55.4	5.54
	3	170	42.5	41.3	4.13
	4	160	40.0	51.2	5.12
	5	210	52.5	53.7	5.37
	6	220	55.0	37.0	3.70
	7	200	50.0	35.1	3.51
	8	210	52.5	49.7	4.97
	9	150	37.5	55.8	5.58
	10	190	47.5	54.0	5.40
	11	130	32.5	34.1	3.41
	12	145	36.3	70.2	7.02
	13	160	40.0	23.9	2.39
	14	180	45.0	51.7	5.17
	15	210	52.5	47.9	4.79
Mulakuzha	16	225	56.3	32.6	3.26
	17	250	62.5	25.3	2.53
	18	155	38.8	38.3	3.83
	19	250	62.5	43.4	4.34
	20	195	48.8	37.2	3.72
	21	220	55.0	32.1	3.21
	22	175	43.8	22.6	2.26
	23	155	38.8	28.4	2.84
	24	185	46.3	48.0	4.80
	25	205	51.3	27.2	2.72
	26	155	38.8	31.0	3.10
	27	150	37.5	24.3	2.43
	28	235	58.8	21.9	2.19
	29	250	62.5	26.1	2.61
	30	190	47.5	30.5	3.05
	31	220	55.0	42.5	4.25
	32	180	45.0	20.6	2.06
	33	160	40.0	29.8	2.98
	34	145	36.3	27.5	2.75
	35	205	51.3	25.1	2.51
Cheriyanad	36	190	47.5	11.7	1.17
	37	200	50.0	53.0	5.30
	38	220	55.0	13.6	1.36
	39	170	42.5	28.2	2.82
	40	200	50.0	11.3	1.13
	41	145	36.3	18.3	1.83
	42	145	36.3	25.8	2.58
	43	135	33.8	10.2	1.02
	44	150	37.5	18.2	1.82
	45	155	38.8	26.4	2.64
	46	210	52.5	35.9	3.59
	47	180	45.0	19.2	1.92
	48	145	36.3	15.5	1.55
	49	160	40.0	27.1	2.71
	50	155	38.8	16.5	1.65
	51	195	48.8	18.6	1.86

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
	52	135	33.8	15.0	1.50
	53	160	40.0	19.8	1.98
	54	170	42.5	17.0	1.70
	55	140	35.0	16.5	1.65
Venmony	56	130	32.5	12.9	1.29
	57	130	32.5	17.9	1.79
	58	140	35.0	19.0	1.90
	59	170	42.5	14.6	1.46
	60	130	32.5	18.2	1.82
	61	160	40.0	21.1	2.11
	62	170	42.5	21.4	2.14
	63	170	42.5	17.3	1.73
	64	140	35.0	16.9	1.69
	65	150	37.5	28.8	2.88
Ala	66	195	48.8	31.7	3.17
	67	170	42.5	20.8	2.08
	68	190	47.5	23.8	2.38
	69	140	35.0	16.9	1.69
	70	150	37.5	28.5	2.85
	71	190	47.5	28.8	2.88
	72	160	40.0	39.3	3.93
	73	185	46.3	16.5	1.65
	74	120	30.0	14.0	1.40
	75	150	37.5	23.0	2.30

Appendix IV

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

Parameters	Fertility class	Percent of samples
pH	Extremely acid	--
	Very strongly acid	34.0
	Strongly acid	28.0
	Moderately acid	27.0
	Slightly acid	11.0
Organic carbon (%)	Low	35.0
	Medium	47.0
	High	18.0
Available P	Low	17.0
	Medium	15.0
	High	68.0
Available K	Low	29.0
	Medium	46.0
	High	25.0
Available Ca	Adequate	25.0
	Deficient	75.0
Available Mg	Adequate	5.0
	Deficient	95.0
Available S	Adequate	--
	Deficient	100.0
Available B	Adequate	95.0
	Deficient	5.0

***** Kerala State Planning Board (2013)