ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 4 IN ALAPPUZHA DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

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(2018-11-043)

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DECLARATION

I, hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 4 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 that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

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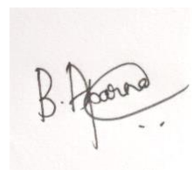

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LIST OF ABBREVIATIONS

%	- per cent
@	- At the rate of
^{0} C	- Degree celsius
β	-Beta
µg	- Microgram
AEU	- Agro Ecological Unit
Al	- Aluminium
B	- Boron
B:C	- Benefit : Cost ratio
C:N	- Carbon : Nitrogen ratio
C:P	- Carbon : Phosphorus ratio
Ca	- Calcium
CEC	- Cation Exchange Capacity
Cl	- Chlorine
cm	- Centimetre
Cu	- Copper
CWC	- Central Water Commission
DAS	- Days After Sowing
dS m^{-1}	- Deci siemens per meter

EC	- Electrical conductivity
ENVIS	- Environmental Information System
et al.	- and others
FAO	- Food and Agricultural Organization
Fe	- Iron
Fig.	- Figure
FRL	- Full Reservoir Level
g	- gram
GIAHS	- Globally Important Agricultural Heritage System
GIS	- Geographical Information System
GOK	- Government of Kerala
GPS	- Geo Positioning System
h	- Hour
H	- Hydrogen
ha	- hectare
ICAR	- Indian Council of Agricultural Research
INM	- Integrated Nutrient Management
K	- Potassium
KAU	- Kerala Agricultural University
kg	- Kilogram

KSBB	- Kerala State Biodiversity Board
KSDMA	- Kerala State Disaster Management Authority
KSPB	- Kerala State Planning Board
LQI	- Land Quality Index
m	- metre
M	- Molar
Max.	- Maximum
MDS	- Minimum Data Set
Mg m^{-3}	- Mega gram per cubic metre
Mg	- Magnesium
mg	- milligram
Min.	- Minimum
ml	- Millilitre
mm	- Millimetre
Mn	- Manganese
MSL	- Mean Sea Level
MSSRF	- M. S. Swaminadhan Research Foundation
MWD	- Mean weight diameter
N	- Normal
N	- Nitrogen

Na	- Sodium
N.I	- Nutrient Index
NRCS	- National Resource Conservation Service
OC	- Organic carbon
P	- Phosphorus
PCA	- Principal Component Analysis
ppm	- parts per million
RHA	- Rice Husk Ash
RSQI	- Relative Soil Quality Index
S	- Sulphur
SAR	- Sodium Adsorption Rate
SMAF	- Soil Management Assessment Framework
SOC	- Soil Organic Carbon
SOM	- Soil Organic Matter
SQ	- Soil Quality
SQI	- Soil Quality Index
USDA	- United States Department of Agriculture
WHC	- Water Holding Capacity
WSA	- Water stable aggregates
Zn	- Zinc

Introduction

INTRODUCTION

Soil quality (SQ) is the inherent capability of a soil to function for specific land uses and it varies from soil to soil (USDA, 2011). The quality of the soil has to be maintained to retain the health of soil and sustain the soil productivity and it is altered by various means like misuse of technologies, application of xenobiotics or poor land management systems. The major causes that reduce soil quality include soil erosion, removal of top soil, floods, droughts, and fires. Flood and subsequent soil erosion influence soil quality by reducing the organic matter content, removal of top soil, decreasing rooting depth and subsequent changes in physical, chemical and biological properties of soil. The flood water contributed by surface runoff will wash out the nutrients, pesticides and fertilizer residues in the agricultural fields and other contaminants from the elevated areas and deposited along with the silt in the low-lying flood prone areas where water remains stagnant for many days. This will alter the soil texture of the frequently inundated areas by depositing fine silts thereby increasing the fertility of soil in flood prone areas. On the other hand, it may also reduce the fertility of soil in certain areas to a great extent through sand casting (Talukdar, 2005).

Kerala, the "God's Own Country" is one among the Indian states which receive a high rainfall with average annual precipitation of 3000 mm. Kerala has mainly two rainy seasons - the South-West monsoon, which is known as Edavapathi and North-East season. Even though pouring rains are a part of the state every year, the South-West season of 2018 had a disastrous impact as the monsoon resulted in rampant floods (CWC, 2018).

In 2018, Kerala experienced an abnormally high rainfall from 1st June to 19th August which accounted for nearly 164 per cent excess over the normal rainfall (CWC, 2018). The incidence of heavy rainfall resulted in flooding at the end of July. All the districts of Kerala except Kasargod were affected by flood. The sporadic effects of intense rainfall caused reservoirs to reach Full Reservoir Level (FRL) and resulted in the release of excess water through flood gates. The excess water released inundated in many parts of Alappuzha, Kottayam, Pathanamthitta, Idukki, Ernakulam, Thrissur and Wayanad districts (Vishnu *et* *al.,* 2019). This flood was the fifth biggest in the world during the five years from 2015, after similar events in China (2016), North-eastern India (2017), Sierra Leone (2017) and Japan during June 2018 which led to exorbitant losses in all sectors including agriculture (Krishnakumar, 2019).

Kuttanad is a special agro ecological unit (AEU 4) which spread over Alappuzha, Kottayam and Pathanamthitta districts. Nearly 57 per cent of the Kuttanad is shared by Alappuzha district, 30 per cent by the Kottayam district and remaining 13 per cent by Pathanamthitta district. Rice, the major crop grown in Kuttanad is cultivated by constructing bunds and dewatering the so formed polders mainly during the Puncha (rabi) season from October-November to January-February (MSSRF, 2007). Kuttanad is divided into 6 agro-ecological zones based on the agro-ecological and climatic characteristics like the height from the mean sea level, influence of rivers, flood risk, risk of saline water intrusion, soil type and fertility and the cropping pattern *viz.,* Kayal lands, Lower Kuttanad, Upper Kuttanad, Purakkad Kari, North Kuttanad and Vaikom Kari.

The Kayal lands constitute 9,464 ha area which is 1.0 m to 2.0 m below MSL. This zone includes Kayal rice fields and are subjected to flood risk and saline water intrusion. Lower Kuttanad is the core area of Kuttanad which is located at the southeastern side of the Vembanad Lake and covers 16,280 ha with most of the area falling in Alappuzha district. Upper Kuttanad zone lies in the south eastern side of Kuttanad which includes comparatively high lands. Purakkad Kari constitutes 3,500 ha of land which spread across 43 padashekharams and situated 1.5 to 2.0 m below MSL. This region is vulnerable to flooding and salt water intrusion through Thottapally spillway and Ambalappuzha - Thakazhy canals. North Kuttanad lies north of Kayal lands and is formed by the natural reclamation of Vembanad Lake due to the silt carried by Meenachil River and its distributaries. It covers an area of 6,556 ha and falls in Kottayam district. The sixth agro ecological zone, Vaikom Kari covers 7,748 ha and falls in Kottayam district located at north of North Kuttanad and includes Vaikkom (Sreejith, 2013).

Kuttanad (AEU 4) was one of the seriously affected areas by the flood. Due to breaching of polder walls, Lower Kuttanad area was under water since July (KSDMA, 2018). Kuttanad is a deltaic formation of four rivers - Achenkovil, Manimala, Meenachil and Pampa. The continuous rise in the water systems of these rivers, absence of appreciable storage reservoirs in the upstream on the above rivers, shrinkage in the carrying capacity of Vembanad Lake and reduction in the capacity of Thottapally spillway have worsened the situation in Kuttanad region (CWC, 2018). The flooding was also aggravated by opening of shutters of three major reservoirs *viz.*, Kakki, Anathodu and Kochu pamba. Agricultural sector has suffered maximum damage due to inundation and sediment deposition which were observed in almost all padashekharams thus resulting in deterioration of physical properties of soils. Muddy water carries suspended silt and clay particles and found to inhibit the infiltration capacity and aeration of the soil. Paddy fields at Kainakary, Nedumudi, Edathua, Champakulam, Ramankary etc. were severely damaged due to the occurrence of rampant floods. According to the report by Kerala State Biodiversity Board, there was an estimated loss of agricultural crops in 5048 ha of land (KSBB, 2019).

Heavy flooding created significant challenges in agricultural lands. The most prominent impact of flood is the deposition of sand and debris on the productive lands which should either tilled into the soil or removed from the field. Erosion of agricultural soil occurred also resulted in the loss of beneficial fungi and other microbes which mobilize soil-based plant nutrients (Wilson *et al*., 2011). There is a dire need to rejuvenate these flood affected soils and improve the quality through various management practices. Hitherto this project is formulated to assess the quality parameters of the flood affected areas in AEU 4 of Alappuzha district with the following objectives.

To assess the soil quality of post-flood soils of AEU 4 in Alappuzha district and to workout soil quality index (SQI).

To develop maps on soil characters and quality using Geographical Information System (GIS) techniques.

Review of Literature

2. REVIEW OF LITERATURE

Soil quality (SQ) is an important character posed by soils which will affect the plant growth. The underlying causes for SQ degradation are largely related to inappropriate land use and soil management, erratic and erosive rainfall, steep terrain, deforestation, and overgrazing. Most of the causes are resulted from a desperate attempt by farmers to increase production for the growing population that aggravate SQ degradation more in the developing countries, which mainly depend on natural resources (agriculture). Misuse of natural resources that leads to degradation can also be stimulated by socioeconomic and political issues, for example, land tenure, capital, and infrastructure. SQ degradation by soil erosion such as soil nutrient depletion and changes in soil physical indicators is largely recognized as a principal cause in most of the developing countries (Lal, 1981).

With respect to Kerala, the occurrence of flood during South-West monsoon season of 2018 had a serious effect on soils of various parts and Kuttanad was one of the drastically affected area. The changes occurred in the soils after the flood has to be studied to tackle the problems caused by the flood. A handful of works were carried out by researchers on soil quality, flood and its effect on soil and physical and chemical characterization of Kuttanad soils. In this chapter an attempt was made to review some of the literatures and research works pertaining to the present study under various subheadings.

2.1 KUTTANAD

Kuttanad, the “Rice Bowl of Kerala”, lies 0.6 to 2.2 m below mean sea level, is a part of the Vembanad wetland, one of the three Ramsar site in Kerala. Kuttanad encompasses vast stretches of backwaters and rice fields which spread over ten Taluks. It contributes nearly 20 per cent of total rice production of the state. Average rainfall in Kuttanad is about 3000 mm of which 60 per cent of rainfall is contributed by South-West monsoon. Most of the areas in Kuttanad are subjected to flooding during monsoon period due to the ingress of fresh water from four rivers and water has to be pumped out to the canal systems and backwaters before the commencement of the cultivation. Brackish water intrusion is experienced during the summer season. Therefore the system is influenced by the runoff water during monsoon and brackish water on other seasons (Kannan *et al.,* 2014). The Kuttanad rice agroecosystem extends from 9° 17'- 9° 40' N and 76° 19' - 76° 33' E and is 0.6 to 2.2 m below mean sea level. It is a floodplain formed by Meenachil, Pamba, Manimala and Achencoil river systems (Thafna *et al.,* 2017).

Kuttanad is a special agro ecological unit which is having a tropical climate with mean annual temperature of 27.6 ^{0}C and rainfall 2,746 mm. Soils of Kuttanad are hydromorphic, often underlain by potential acid sulphate sediments and unique hydrological conditions that characterize the unit (KAU, 2016). Kuttanad represents waterlogged lands which spread over 69 panchayats of Alappuzha, Kottayam, and Pathanamthitta districts. It is considered as the "Rice Bowl of Kerala" having 55,000 ha of paddy fields. This agro-ecological region is a part of the Vembanad wetland system, a Ramsar site of international importance (Sruthi *et al.,* 2017).

Kuttanad, the major rice granary of Kerala is one of the regions of the world which produces rice at below mean sea level. It is a unique ecologically fragile bio-geographical unit. Physicochemical properties of the soils of Kuttanad show wide degree of variation. Based on biochemical characteristics and geological features, Kuttanad soils are categorized into three regions; Upper Kuttanad, Lower Kuttanad and 'Kayal' fields. These regions do not have a well-defined boundary and they are quite overlapping in nature (Ray *et al.,* 2014).

Kuttanad soils are low to medium in fertility, alluvial with silty clay texture and are enriched by annual silt deposition during the monsoon floods. The most important constraints of the system is attributed to the problems of water logging, saline water intrusion, soil acidity along with climatic variations. Crop damage due to summer rains and floods during monsoon in the low-lying paddy fields are common in Kuttanad. This uniqueness has earned it the status of a Globally Important Agricultural Heritage System (GIAHS) by FAO in 2013 (ICAR, 2017).

2.1.1 Soils of Kuttanad

Soils of Kuttanad are broadly classified into Kayal, Karappadam and Kari lands which comprises about 75000 ha of land which is spread over the three districts of Kerala. Kayal soils are slightly acidic and low in organic matter content whereas Kari and Karappadam soils are highly acidic and rich in organic matter. Water logging and saline water intrusion are the major constraints of these areas and they influence the soil reaction and soluble salt content in the soil (Kurup and Aiyer, 1973).

Karappadam soils comprises 33000 ha of land which are river borne alluvial soil occur along the inland waterways. These soils spread over a large part of Upper Kuttanad which is characterized by high acidity, high salt content, low nutrient availability particularly phosphorus, high percentage saturation of hydrogen and aluminium. These soils are thus considered as highly problematic soils with poor drainage (Liji, 1987).

Kari soils are seen in patches in Alappuzha and Kottayam districts below sea level and are deep black, extremely acidic, poorly drained and covers an area of 9000 ha. Kari soils are mostly seen in Lower Kuttanad region. These soils are low in fertility and contain Fe and Al in toxic concentrations. Salinity and acidity of Kari soils increase with increase in depth (Thampatti, 1997). The unique characteristic of Kari soil is the coexistence of acidity and salinity. Salinity problems in Kari soils are due to the direct access to sea and inundation of salt water from sea. These soil on oxidation will produce sulphuric acid which cause extreme acidity to the soils and named as acid sulphate soils. Presence of partially decomposed organic residues and fossil woods are reported in this area (Mathew *et al.*, 2001).

More than two third of the total land area in Kuttanad is wetlands. The wetlands in Kuttanad are submerged in water for most part of the year and have poor in drainage. Soils of Kuttanad are enriched by the silt deposited through the river systems of Meenachil, Pamba, Manimala and Achencoil. The loamy soil in this region is very fertile and highly suitable for paddy cultivation (Thomas, 2002).

Kayal soils cover the reclaimed areas of Kuttanad which are mainly fluviatile alluvium overlain by lacustrine deposits. These soils are deep, poorly drained with dark brown colour with a white colouration on the surface due to presence of salts. Kayal soils are low in nutrients but fairly rich in calcium deposits. Soil texture of Kayal soils varies from silty loam to silty clay loam on the surface (John *et al.*, 2009).

Karappadam soils are formed by the transportation activities of rivers and are rich in organic content, strongly acidic, poor in plant nutrients particularly phosphorus. The important features of this soil are presence of decomposed organic materials and high salt content. Kari soils are deep black in colour with half decomposed organic matter. Heavy texture, poor aeration, impeded drainage and low content of plant nutrients are the characteristic features of Kari soil (ENVIS centre, 2014).

The acid sulphate soils of Kuttanad covers an area of 14,227 ha and have a pH below 4. Ambalappuzha, Kallara, Thakazhi, Thottappalli and Purakkad belong to the acid sulphate series of Kuttanad. Soils with extreme acidity and presence of iron and aluminium in toxic concentrations are the unique distinguishing characteristics of these soils (Beegum, 2016).

2.1.2 Physical properties

Soil texture is the fundamental soil physical property controlling water, nutrient, and oxygen exchange, retention, and uptake. It is a master soil property that influences the most other properties and processes. Soils of Kuttanad are mixtures of clay and sand in different proportions (GOK, 1971). Santhakumari (1975) studied the morphological and physiochemical properties of Karappadom soils of the Kuttanad region and reported that the soils can be texturally classified into clay, loamy sand, silt and silty loam.

Anup (1996) reported that texture of Kuttanad soils ranging from silty clay loam to clay and exhibits a regular decrease in fine sand with depth. Silt content also shows decrease from top to 2^{nd} horizon and remains more or less same in subsoil.

A study was conducted by Thampatti and Jose (2000) to characterize the acid saline soils of Kuttanad revealed that sand recorded a highly significant and negative correlation with water holding capacity of soil (-0.657*) and pore space (-0.735**) whereas silt, clay and organic carbon showed significant positive relationship with above soil properties. Sand recorded significant and positive correlation with hydraulic conductivity, absolute and apparent specific gravity, and clay and silt were negatively correlated with the above characteristics. About 72 per cent of the tract belonged to soil subgroup Typic Sulfaquents and seven per cent each to Typic Tropopsamments, Typic Fluvaquents, Typic Tropoi1uvents and Fluventic Dystropepts. A definite pattern of distribution of sand, silt or clay was not observed for the pedons belonging to Typic Sulfaquents, Typic Tropoi1uvents and Fluventic Dystropepts. The other physical parameters like apparent and absolute specific gravity, porosity, water holding capacity, and hydraulic conductivity do not follow a uniform pattern in most of the soil subgroups.

Beena (2005) reported that among the six acid sulphate soil series of Kuttanad, the clay content was the highest in Thuravur series with a value of 52.4 per cent while sand and silt content were highest in Thottapally and Ambalappuzha series respectively. Water holding capacity of acid sulphate soils of Kuttanad ranged between 40 to 65.3 per cent and highest water holding capacity is reported in Thuravur series.

Sruthi *et al.* (2017) analysed the soil samples from Kuttanad agroecosystem and opined that the soil texture varied from sandy to sandy loam, loamy sand and sandy clay loam.

Bulk density and particle density have great importance in understanding the physical properties of soil. Among the six acid sulphate soil series in Kuttanad, the mean values of bulk density at surface soil ranged from 0.61 to 1.06 Mg m^{-3}. The highest value observed in Ambalappuzha series and the lowest value in Kallara series. Particle density of acid sulphate soils of Kuttanad ranged from 1.19 to 2.04 Mg m^{-3} and highest value was recorded in Ambalappuzha series. Available water holding capacity measures the relative capacity of a soil to supply water and its mean value varied from 48.31 to 48.44 per cent (Nath, 2016).

2.1.3 Chemical properties

2.1.3.1 pH and EC

Subramoney (1960) opined that high acidity in Kari soils of Kuttanad is due to the production of sulphuric acid by the oxidation of iron sulphides present in the soil.

Kurup and Aiyer (1973) studied the seasonal variations in soil reaction and soluble salt content of Kuttanad rice soils and reported that both pH and EC shows seasonal fluctuations in Kari, Karappadam and Kayal lands. Maximum pH values were recorded during October - November and minimum pH values during summer months. The lowering of soil pH during summer months is attributed by the oxidation of iron sulphides present in the soil and subsequent release of sulphuric acid. Seasonal fluctuations of soil pH is predominant in Kari soils, moderate in Karappadam soils and least in Kayal soils.

Potential acid sulphate soils are rich in pyrite (FeS_2), which on drainage and exposure to air oxidizes to sulphuric acid and converts to actual acid sulphate soils. Due to oxidation of reduced sulphur compounds in pyritic mud, these soils are characterized by low pH, high aluminium, iron and sulphate contents (Van Breemen and Pons, 1978).

Van Mensvoort *et al.* (1991) reported that in acid sulphate soils $A1^{3+}$ can be substituted by Na^{+} and Mg^{2+} in salt or brackish water which will help to lower the exchangeable acidity of the soil.

Cicy (1989) reported that the soils of Kuttanad were acidic in nature with a mean pH value of 3.92. Among the three soils, Kari soils were extremely acidic and the lowest pH value recorded was 2.7. The EC of the soils ranged from 0.3 to 13.0 dS m^{-1} and most of the Kari soils were saline in nature.

Electrical conductivity provides an estimate of total soluble salts. EC shows seasonal variation in Kari, Karappadam and Kayal lands. Electrical conductivity of Kuttanad soils was maximum during March to April and minimum during October to November. Increase in electrical conductivity of all the three types of soil during summer months are due to the increase in salinity in the lake water and capillary rise of soluble salts from the subsoil.

Seasonal fluctuations of soluble salts in the soil is maximum for Kayal soils when compared to Kari and Karappadam soils (Kurup and Aiyer, 1973).

The electrical conductivity was negatively correlated with pH of the soil. Kuttanad soils show a higher level of organic carbon with a mean value of 2.97 per cent. Increase in organic matter content caused an increase in EC and pH of the soils (Cicy, 1989).

Thampatti and Jose (2000) reported that EC was low for surface layers and subsurface layers showed still higher values due to the accumulation of salts in lower layers. Even though the lower layers showed higher values, none of the soil subgroups showed a definite pattern for it. The tidal and fluvial effect varied with the climate in each year and this resulted in variation in chemical characteristics. Considerable reduction in electrical conductivity was noted in the area during the post-barrage period than pre-barrage period.

The prevention of saline water intrusion from the sea, which was the major source of salts, had decreased electrical conductivity of these soils. Extremely saline soils have changed to mildly saline soils. Nair and Pillai (1990) reported 90 per cent reduction in salinity during the months of March to May compared to that of pre-barrage period.

Mathew *et al.* (2001) reported that EC of acid sulphate soils are higher during summer and the recorded a value of 6 dS m^{-1}. Nath (2016) studied the different series of sulphate soils of Kuttanad and opined that soils of all series are extremely acidic with pH less than 4.5 and EC of the soils ranged from 0.14 to 7.52 dS m^{-1}.

Beena and Thampatti (2013) studied the acidity characteristics of acid sulphate soils of Kuttanad and revealed that the potential acidity of surface soils varied from 32.87 to 110.5 cmol $^{(+)}$ kg^{-1}. The potential acidity is consists of hydrolytic acidity and exchangeable acidity and the dominant is hydrolytic acidity which contribute 70.22 to 97.20 per cent of potential acidity. The exchangeable acidity of soils varied from 1.23 to 8.10 cmol $^{(+)}$ kg^{-1}.

The physical and chemical characteristics of acid saline rice soils of Kuttanad were evaluated by Thampatti and Jose in 2000 with special reference to salinity protection by Thanneermukkom regulator by comparing the present soil characteristics with that of pre-barrage period. They reported that the closure of the regulator during the summer for the past 23 years had altered many soil chemical properties and opined that most of the physical properties remained unaffected.

2.1.3.2 Organic carbon

In general, the soils of Kuttanad region of Kerala are rich in organic matter content. This naturally resulted in high organic carbon status in these soils. In soil test based recommendation, nitrogen is applied based on the organic carbon status assuming that the C: N ratio tend to stabilize at 10:1. The organic carbon based nitrogen recommendation is relied on for fertilizer recommendation because more than 95 per cent of nitrogen in soil exists in organic form associated with organic matter (Nair and Pillai, 1990).

Stott *et al.* (1999) explained that hydrologic regime played a role in organic matter accumulation. Kuttanad soils are rich in organic matter content with an average value of 4.63 per cent and organic carbon content varied from 5.35 to 17.55 as per the findings of Usha and Varghese (2002).

Lal (2002) found that high organic matter content is also due to water stagnation associated with rice cultivation. Among the six acid sulphate soil series, organic carbon was found to be high for Purakkad series (Beena, 2005). Grybos *et al.* (2009) opined that low pH favors low oxidation of organic carbon leading to its excessive accumulation, which corresponds to high organic carbon in Kuttanad soil. Similar findings were also reported by Kannan *et al.* (2014) from the Kuttanad soils and opined that organic carbon content ranges from 2.79 to 7.70 per cent. Water logging associated with rice cropping might also enhances the accumulation of organic carbon.

The study conducted by Beegum in 2016 revealed that the organic carbon content of Kuttanad soils was high and ranged between 1.73 to 6.20 per cent and the highest organic carbon content was recorded in Kallara series. Dhanya (2017) assessed the soil organic pools of acid sulphate soils of Kuttanad and the study revealed that the inorganic carbon fraction was not present in any of the soil series. The total organic carbon content was significantly influenced by different land uses.

A study on the acid sulphate soils of Kuttanad by Aparna *et al.* (2020) revealed that the highest organic carbon and organic matter content was reported by the Kallara surface and lowest at Purakkad sub surface. The reason for the increased organic carbon and organic matter content in acid sulphate soils of Kuttanad can be attributed to the luxuriant growth and decaying of the macrophytes.

2.1.3.3 Nutrient status

Kuttanad soils are low to medium in fertility and are enriched by annual silt depositions from the four river systems. These soils in general are dark brown to black in colour and are sticky with lime shell deposits in these areas (Smitha, 2017).

Kuttanad soils are low to medium in nitrogen availability. Pillai (1964) opined that available nitrogen in Kari soils varied from 140 to 590 mg kg^{-1}. Beegum (2016) found that available nitrogen content in acid sulphate soils of Kuttanad ranged from 61.15 to 310.01 kg ha^{-1} with highest value recorded from Kallara series.

Thafna *et al.* (2017) studied about the distribution of nutrients in the soils of Kuttanad and reported that the mean value of available nitrogen content in the paddy fields of Kuttanad comes under high fertility status (771.91 kg ha^{-1}). Among the total 92 sites studied, 15 sites were medium in fertility with available nitrogen content ranging from 272 to 544 kg ha^{-1} and 77 sites fall within high fertile class.

One of the major problem associated with Kuttanad soils is the deficiency of available phosphorus content. Cicy (1989) conducted a study on Kuttanad soils and reported that kuttanad soils were low in available P and their values ranged from 1.2 to 10.3 ppm. Available phosphorus was positively correlated with pH and negatively correlated with EC and organic carbon present in the soil. Thampatti (1997) reported that about 67 per cent of Kuttanad soils are deficient in phosphorus. Toxicity of Al decreases P availability by producing complexes with Fe and Al (Ward *et al.,* 2008).

Thafna *et al.* (2017) reported that the availability of phosphorus in Kuttanad soils were low with a mean value 0.71 kg ha^{-1}. The availability of phosphorus found to increase with soil pH and decrease with organic carbon and conversion available form of phosphorus to unavailable form due to the addition of organic matter with wide C : P ratio was also reported.

Potassium, one of the primary nutrients which is associated with translocation of water and minerals show high status in Kuttanad soils. Thampatti and Jose (1997) reported that available potassium content in the acid sulphate soils of Kuttanad increases with depth and the mean values varied from 83 to 251 mg kg^{-1}.

Available potassium content in Kuttanad soils reported to be high with mean value 322.32 kg ha^{-1}. The application of rice straw found to significantly increase available potassium content in soil by increasing organic matter contents. Soil organic matter play a major role in holding and supply of potassium (Thafna *et al.*, 2017).

Calcium and magnesium content of Kuttanad soils are high compared to other acid soils of Kerala due to the frequent addition of liming materials and marine origin of the area. Mean values for available calcium varied from 172 to 788 mg kg^{-1} and that of magnesium ranged from 172 to 788 mg kg^{-1} in surface soils (Thampatti, 1997). Ray *et al.* (2014) studied the fertility status of Kuttanad soils in relation to seasons and different stages of paddy cultivation and reported that calcium content Kuttanad soils ranged from 441.4 to 3858.80 kg ha^{-1}. The highest amount of calcium (3858.80 kg ha^{-1}) was observed during Puncha cultivation, at seedling stage in Upper Kuttanad and the lowest value was observed during panicle initiation stage in Upper Kuttanad. Magnesium content in these soils ranged from 177.7 to 992.1 kg ha^{-1} with highest value recorded from at panicle initiation stage in Kayal soils during Puncha season.

Soils of Kuttanad are rich in sulphur content due to the presence of sulphur containing minerals present in the soil. Cicy (1989) studied about the sulphur status of Kuttanad soils and opined that Kuttanad soil contain large amount of water soluble sulphur whose value ranged from 25-395 ppm. Maximum content of water soluble S was reported in Kari soils.

Acid sulphate soils of Kuttanad are rich in sulphur content and among the six acid sulphate soil series, highest sulphur content was reported in Thuravur series (550.48 kg ha^{-1}) (Beegum, 2016).

2.1.3.4 Micronutrients

Micronutrient status of Kuttanad soils were studied by Aiyer *et al.* (1975) and revealed that soils of Kuttanad are deficient in available copper (90 per cent) and zinc found to be deficient in 50 per cent of Kayal soils. Toxicity of iron is reported in all the three types of soil and maximum value for available iron was reported in Kari soils.

Hot water extractable boron content is the best index to identify plant available boron present in the soil. It was reported that boron is an essential element for plant growth whose concentration range in soil solution to cause sufficiency or deficiency to plants is comparatively narrow. Boron is easily adsorbed by soil and become unavailable to the plants. Soil pH, clay content, surface area and organic matter content are the chief properties of soil which affect boron availability. Boron availability in more in fine textured soils when compared with coarse textured soils (Bingham, 1982).

Anu (2011) studied on the availability indices of boron in major soil groups of Kerala and reported that Kuttanad soils have adequate levels of available boron and among the eight soil types under study, total boron content was high for Kuttanad soils.

Beegum (2016) opined that available iron and manganese content of acid sulphate soils of Kuttanad are significantly high and available copper and zinc content are low. Mean value of available iron content ranged from 1452.82 to 3039.48 mg kg^{-1} and that of manganese ranged from 6.25 to 15.58 mg kg^{-1}.

Devi *et al.* (2017) carried out a study in Vaikom Kari soils of Kuttanad to evaluate the availability of micronutrients *viz.*, Fe, Mn, Zn, Cu and B as influenced by soil acidity amelioration practices for rice. The treatments for the study included lime, dolomite and rice husk ash (RHA) applied as two splits one as basal and 30 DAS and the other as basal and one week before panicle initiation stage and a control without ameliorants. The results of the study revealed that availability of micronutrients are greatly influenced by acidity amelioration practices except for Zn. The soil which was initially contained toxic levels of iron showed significant reduction in available Fe with lime treatments. Higher value for available Mn was recorded by lime or dolomite treatments. Soil available Cu status was the highest with control at panicle initiation stage and with dolomite as basal + panicle initiation at harvest stage.

2.1.4 Biological properties

Microbial activity have great impact on biological and biochemical soil processes due to its direct influence on the transformation of nutrients. It is associated quantitatively and qualitatively with the presence of extracellular hydrolytic enzymes which are important for decomposition and mineralization of organic matter (Kiss *et al.,* 1975; Nakas *et al.,* 1987; Martens *et al.,* 1992; Elliott *et al.,* 1993).

Enzyme activities in soil are widely used as an index of soil fertility since they are involved in the biological transformations of native and foreign compounds in soils (Tate, 2000). Soil enzymes play significant role in maintaining soil health. The enzymatic activities present in soil are mainly of microbial origin. They are reliable indicators of soil health, as they have active effects on nutritional cycling, affecting the physical and chemical properties of soil. Microorganisms respond quickly to minute changes in soil by altering their population and activities, and thus, can be used for soil health assessment. Soil enzymes are the direct effect on biological catabolism of organic and mineral components present in soil. The potential enzymes which play significant roles in soil health maintenance are - amylase, arylsulphatase, β-glucosidase, cellulase, chitinase, dehydrogenase, phosphatase, protease, and urease (Das and Varma, 2010).

Dick and Tabatabai (1993) opined that phosphatase activity in soil is an indicator of organic phosphorus mineralization potential and biological activity of soils. An inverse relationship was observed between soil available phosphorus and acid phosphatase activity. From the study by Bergstrom *et al.* (1998) it is inferred that the surface soil exhibited higher activity than sub surface soils. It is also noticed that there is higher enzyme activities in the surface soil than the sub surface because of the increased organic matter content.

Nath (2016) studied the enzyme characterization of acid sulphate soils of Kuttanad and reported that activity of acid phosphatase varied significantly with the locations and the mean values varied from 24.59 to 57.58 µg of p-nitrophenol released g^{-1} soil h^{-1}. Among the five acid sulphate series, highest acid phosphatase activity was reported in Purakkad series. Urease activity of Kuttanad acid sulphate soils ranged from 57.51 to 75.78 ppm of urea hydrolyzed g^{-1} of soil h^{-1} and the highest mean value was recorded by the Thakazhi series.

2.2. EFFECT OF FLOOD ON SOIL

Flooding is the submergence of soil which is normally dry which affects the physical, chemical and biological properties of soil. Major effects of flood on the physical properties of soil include restriction in soil aeration, swelling of clay colloids, and destruction of soil structure. Flooding will restrict gaseous exchange between soil and atmosphere which leads to accumulation of carbon di oxide, methane and hydrogen in soil. A good soil structure is important to provide aeration and drainage in soil and maintain soil health. Flooding will destroy soil structure by disrupting soil aggregates. The disruption of aggregates are due to the uneven swelling of clay colloids, pressure buildup in soil by entrapped air and destruction of cementing materials (Ponnamperuma, 1972).

During flooding soil solution get diluted and increase soil pH. Increase in soil pH is mainly due to the reduction of Fe (III) to Fe (II). Flooding will increase the specific conductance in non-saline soils (Ponnamperuma, 1972).

In flooded soils, nutrients like sulphate and nitrogen can easily leach out of the soil and deposition of heavy metals can be there (Reddy and Rao, 1983; Burt and Arkell, 1987). Under submerged conditions, nitrogen mineralization stops at ammonium formation stage because of the lack of oxygen. As a result ammonium builds up in flooded soils (Ponnamperuma, 1982).

During flooded condition the pH of most soils tends to approach towards neutral point, with acid soils increasing and alkaline soils decreasing in pH. The tendency for soils to approach a neutral pH when submerged indicates that the pH of a submerged soil is buffered around neutrality by substances produced as a result of reduction reactions (Patrick *et al.,* 1985).

Flooding will create an anaerobic condition in soil and anaerobic organisms will replace aerobic organisms. Anaerobic organisms, mainly bacteria cause denitrification and reduction of manganese, iron, and sulphur. The decomposition of organic matter done by anaerobic bacteria in flooded soils. These organisms are less diverse and inefficient in decomposing organic matter. As a result slick, slimy layers of partially decayed organic matter may be produced (Coder, 2008).

2.2.1 Occurrence and impact of flood in Kuttanad

Kuttanad face incidence of floods at intermittent intervals. The Kuttanad wetlands extend from the southern part of Vembanad Lake with its outflow controlled by the Tanneermukkom Barrage and the polder areas south of the lake with a southern boundary of the Pamba river and an outlet canal controlled by the Thottappally spillway which block saline water intrusion into rice fields and help in discharge of floodwaters from Kuttanad. 25 per cent of total area of Kerala is prone to floods which includes Kuttanad, kolelands and other low lying areas. (Chattopadhyay and Franke, 2006).

Commonly known as the “Venice of East,” for its rich backwaters and paddy fields set like jewels upon the crown of Alappuzha, it also has unique geographical traits. Situated 2.2 m below sea level, the abode of Vembanad - the largest lake in the state which stretches from

Alappuzha to Ernakulam district and is dotted with houseboats is also home to a variety of unique flora and fauna. Another peculiarity of this terrain is the four major rivers - Pampa, Manimala, Meenachil, and Achankovil that run through it. These rivers and lakes help the land abound with fertility and aid water-intensive paddy cultivation. However, these water bodies also often distress people with constant floods and droughts. Poor drainage facilities is one of the prime reasons for the floods, and has not yet been dealt with. The role of unscientific road construction, which has curtailed the natural flow of streams and rivers, is undeniable in this catastrophe. In the land of backwaters and the abode of the largest fresh water lake in the state, people were struggling to access fresh drinking water, with those in isolated regions having to travel around seven kilometers on rowboats to get to drinking water (Menon, 2018).

More than 50 per cent area of Alappuzha is prone to flood and most of these area is confined to Kuttanad due to its unique geographic condition. Kuttanad region was drastically affected by the heavy rainfall and flood during 2018. About 130 households were completely damaged and 656 households were partially damaged during the flood. Flood water inundation and sedimentation were occurred in Kuttanad which has destroyed the physical status of the padashekharams. Some beneficial effects were also brought by the flood and resultant sedimentation to the area which was seen during the next cropping season. The agricultural production was almost doubled in the next cropping season with rice showed a bumper yield (GOK, 2018a).

2.3 SOIL QUALITY

Soil quality is regarded as the capacity of soil to function within its ecosystem boundaries and is considered as the prime element for sustainable production of crops. Soil quality is assessed by the properties exhibited by the soils. Basic idea behind soil quality was the fitness of soil for a specific use. Based on Leopold’s definition on soil fertility, Anderson and Gregorich proposed a definition for soil quality. According to Anderson and Gregorich (1984) the capacity of soil to receive, reserve and recycle water and nutrients is soil quality.

Over the last decade agriculture was considered as a part of ecosystem and the concepts for soil quality also changed. Larson and Pierce (1991) defined soil quality as a part of ecological system that interacts with other parts of the system. According to them soil quality is the capacity of soil to function within the boundaries of ecosystem to positively interact with its external environment.

The Soil Science Society of America (1995) defined soil quality as the capability of a particular soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity and maintain water and air quality and support human health. Gregorich and Acton (1995) defined soil quality in an agricultural context as the capacity of the soil to support crop growth without harming the environment.

Karlen *et al.* (1997) suggested the definition of soil quality as the ability of soil to function within natural and managed environment to sustain both plant and animal productivity and maintain or enhance water and air quality, and support human health and habitation.

2.3.1 Types of soil quality

Soil has both inherent and dynamic soil quality. The quality of soil which is attributed by intrinsic characteristics of the soil is inherent soil quality. They are almost static and show small variation over time. They cannot be evaluated independent of extrinsic factors (Pierce and Larson, 1993).

Dynamic soil quality comprises those properties which change in response to human use and management. Choices of management practices will affect the amount of soil organic matter, soil structure, soil depth, and water holding capacity of soils. Response of soils to management differ depending on the inherent properties of the soil and the surrounding landscape (Larson and Pierce, 1994; Carter *et al.,* 1997).

Soil quality focuses more on the dynamic soil properties which is strongly influenced by management practices and are monitored in the top 20 to 30 cm of the soil (Karlen *et al.*, 2003).

2.3.2 Soil quality indicators

Soil quality assessment is dependent on the development of soil quality indicators which influence a specific function. The selected indicators can be qualitative to quantitative measure of soil physical, chemical and biological status of the soil. The basic soil quality indicators selected to workout soil quality should integrate soil physical, chemical, and biological properties and processes. It should encompasses ecosystem processes and applicable to field conditions. The indicators must be sensitive to variations in management and climate (Doran and Parkin, 1994).

Soil quality indicators are broadly classified into physical chemical and biological indicators.

2.3.2.1 Physical indicators

Physical indicators will provide information on soil water characteristics like water entry and retention that influences availability to plants. Common physical indicators used includes soil texture, aggregate stability, available water capacity, bulk density, infiltration, slaking, soil structure etc. (USDA, 1996).

2.3.2.1.1 Soil texture

Soil texture is one of the stable attributes of soil. Soil texture affect moisture retention, hydraulic conductivity and bulk density of a soil (Arshad and Coen, 1992). White (1997) opined that the soil texture is one of the natural soil physical properties less affected by management. It also reflects the water and nutrient holding capacity of soil. More the clay content more will be the ability of soil to retain water content. Six *et al.* (2002) indicated that the clay minerals with a higher cation exchange capacity (CEC) and large surface area have a greater potential to bind with soil organic matter than clays with lower CEC and smaller surface area.

2.3.2.1.2 Bulk density

It is an indicator for soil compaction and reflects the ability of soil to function for structural support, water movement, and soil aeration. It is a dynamic property which varies with cultivation practices, soil organic matter content and structural characteristics. Soil properties like moisture retention, root development, nutrient cycling are negatively influenced by high bulk density values (Arshad and Coen, 1992; Arshad *et aI.*, 1996). For most of the soils, bulk density ranged from 0.8 to 1.6 Mg m^{-3}. Arvidsson (1998) reported that bulk density will decrease with increase in organic matter content and clay content and increase with sand content in the soil. Bulk density decreases with depth due to decline in organic matter content, less aggregation and root growth and increased compaction (Juo and Franzluebbers, 2003). Gupta (2004) reported that bulk densities of soils are inversely related to the quantity of pore space and soil.

2.3.2.1.3 Particle density

Particle density is one of the fundamental physical properties of soil whose values varies from 2.5 to 2.8 Mg m^{-3}. Hillel (1980) reported that particle density of soil influence soil porosity and aeration. Presence of iron oxide and minerals increases soil particle density and the presence of organic matter lowers particle density.

2.3.2.1.4 Porosity

Soil porosity influence root penetration, physical behavior and movement of water in soil. Foth (1990) described that total porosity of soils generally varies between 30 per cent and 70 per cent. For soils with the same particle density, higher porosity is reported in soils with lower bulk density. Fine textured soils are highly porous than coarse textured soils. Macropores dominate in coarse textured soils and micropores dominate in fine textured soils. Intensive cultivation causes soil compaction and degradation of soil porosity. The lowest porosity is the reflections of the low organic matter content in the soil (Brady and Weil, 2002).

2.3.2.1.5 Water Holding Capacity

Tisdale *et al.* (1995) stated that soil water content affects various soil physiochemical reactions and supplies essential nutrients to plants. Water holding capacity of soil is greatly affected by soil organic matter content, texture, and soil morphology. Fine textured soils mainly contains fine particles like silt and clay which have higher surface area compared to sand fraction and these soils hold more water than coarse textured soils.

Water holding capacity of soil is mainly controlled by the number of pores and pore-size distribution of soils, and by specific surface area. With an increase in organic matter content in soil, there is increased aggregation and decreased bulk density and enhanced the total pore space as well as the number of small pore size (Haynes and Naidu, 1998).

Addition of organic matter to the soil is found to have positive effect on water holding capacity. The increase in water holding capacity of soil by addition of organic matter is due to the increase in the number of micropores and macropores in the soil either by "gluing" soil particles together or by creating favorable living conditions for soil organisms (Brady and Weil, 2002).

2.3.2.1.6 Aggregate stability

Ability of soil to resist beating and slaking action of water is an important property of soil in relation to the capacity of soil to maintain a porous structure. Aggregate stability of soil is strongly correlated with the presence of organic matter in soil (Tisdall and Oades, 1982).

Munroe and Kladivko (1987) reported that soils with higher initial soil water contents had greater aggregate stability when compared to soil samples having lower initial water content and air-drying of aggregates reduce their stability.

Shainberg *et al.* (1992) reported that disintegration of the soil macro-aggregates into micro-aggregates is independent of soil electrical conductivity and is produced primarily by the beating and wetting action of water. Aggregate stability is influenced by clay mineralogy but its effect is hard to quantify as the soils contain a mixture of clay minerals.

Presence of calcium carbonate in soil have a positive impact on soil aggregation. For a beneficial aggregating effect, sufficient clay should be present and calcium carbonate particles should be smaller than that of silt particles (Le Bissonnais, 1996). Sesquioxides have a stabilizing effect on soil aggregates and will bind clay particles to organic molecules thus have the ability to precipitate as gels on clay surfaces (Amezketa, 1999).

2.3.2.2 Chemical indicators

The chemical indicators are total organic carbon and nitrogen, pH, electrical conductivity and extractable N, P and K (Stott *et al.*, 1999). Chemical indicators of soil quality will provide information on the equilibrium between soil solution (soil water and nutrients) and exchange sites (clay particles, organic matter), plant available nutrients, plant health and levels of soil contaminants and their availability for uptake by animals and plants (USDA, 2015).

2.3.2.2.1 Soil pH

It is the most informative measurement of soil which is made to describe and determine the soil characteristics. pH, a measure of H^+ ion concentration is used to estimate lime requirement of the soil, possible availability of phosphorus and other minor nutrients like zinc, boron, copper etc. to the crops. Soil pH close to 2 to 3 indicates the presence of mineral acids, usually sulphuric acid in the soil. A soil with pH of two to three always found to have a continuous supply of free acid and the major source are the pyritic minerals which on oxidation produce sulphuric acid. At pH four to five presence of exchangeable trivalent aluminium ions are reported in mineral soils. At pH 5.5 and above exchangeable trivalent aluminum ions will be replaced by complex mixture of hydroxy-Al ions, many of them are highly polymerized. Soil salt content is a major factor that affect soil acidity. The normal tendency of the salts is to reduce the soil pH progressively with increase in salt concentration. In acid soils it is done by both displacement of AI^{3+} from the exchange complex and hydrolysis of various type of AI species in the presence of salt (Ragland and Coleman, 1960).

Anderson and Nilsson (2001) stated that soil pH will affect the organic carbon accumulation in soil. At lower pH the activities of soil micro-organisms that decompose organic matter is inhibited and so can lead to the preservation of organic matter inputs into the soil.

2.3.2.2.2 Electrical Conductivity

Soil electrical conductivity (EC) is a numerical expression of the ability of soil water to carry an electric current. Ions like Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^- and CO_3^{2-} in the form of salts dissolved in soil water will increase EC of soil as they posses electric charge. Electrical conductivity of soil is affected by both intrinsic and extrinsic factors. Intrinsic factors include soil texture, porosity, soil moisture, amount and type of soluble salts in solution, and soil temperature. EC of soil increases with increase in porosity and clay content of soil. At higher porosity, the ability of soil to conduct electrical current will be higher due to high moisture content. EC is also affected by presence of soil organic matter and type of fertilizer applied (USDA, 2011).

Bruckner (2012) reported that pH and EC are negatively related functions. Lower soil pH indicate the presence of larger number of hydrogen ions in the soil which will increase electrical conductivity.

2.3.2.2.3 Soil organic carbon

Soil organic carbon (SOC) is the carbon stored in soil organic matter. Amount and nature of SOC play a key role in soil quality (Larson and Pierce, 1994). Raupp (1999) studied the effect of manures and mineral fertilizers on the maintenance of SOC under long-term trial and reported that organic carbon content to be higher with manure (0.90 per cent) than with mineral fertilization (0.79 per cent). The factors which affect soil organic carbon includes addition of organic amendment, the amount and stage of decomposition of plant residues, soil texture, climate and time. Soils rich in clay content will protect SOM from further decomposition by stabilizing substances that bind to clay surfaces (USDA, 2009a).

2.3.2.3 Biological indicators

Soil biological indicators provides an idea of the living component present in the soil. Biological indicators have strong relationship with soil functions and used to assess soil quality. Biological indicators are dynamic soil properties that are altered by natural disturbances, land management, and chemical contaminants. Common biological indicators used for soil quality assessment includes measurements of micro and macro organisms and their activities. Concentration or population of earthworms, nematodes, termites, ants, as well as microbial biomass, fungi, actinomycetes, or lichens can be used as indicators. Biological indicators also include properties associated with biological activity on organic matter, such as microbial biomass carbon and soil respiration (USDA, 2009b).

2.3.3 Assessment of soil quality

Soil quality is assessed by considering soil physical, chemical and biological properties which serve as indicators for a specific soil function and their variation with time (Larson and Pierce, 1991).

Pierce and Larson (1993) introduced a method to assess soil quality by establishing minimum data set of soil properties and pedotransfer functions which are temporarily variable. Input data for this method is taken from available soil surveys and simulation models will be used to design sustainable management systems.

A soil quality test kit was developed by Doran *et al.* (1996) to provide understanding on how soil physical, chemical, and biological properties and processes change with time and from one location to another. The kits were used to measure water infiltration, bulk density, soil respiration at field capacity, soil water content, water holding capacity, water-filled pore space, soil temperature, soil pH, electrical conductivity, and soil nitrate.

NRCS-Soil Quality Institute have developed score cards for soil quality assessment and their guidelines .It was one of the earliest method for assessing soil quality (USDA, 1999).

USDA (2001) developed soil quality test kit that can be used to assess soil quality in the field. The test include the measurement of soil respiration, infiltration, bulk density, electrical conductivity, pH, EC, nitrate content, aggregate stability, earthworm counts and penetration resistance. It allows to assess the effects of different mulch treatments on soil quality, and allows us to quantify soil quality changes over time.

Andrews *et al.* (2004) developed Soil Management Assessment Framework (SMAF), as a new method for implementing the concepts of soil quality, soil health and their assessment which is an additive, non-linear indexing tool. The three steps involved in SMAF are selection of indicators, their interpretation and integration into soil quality index. The selection of indicators are done on the basis of expert system of decision tools to recommend indicators suited for the current study. For interpretation, the indicator data are transformed into unitless scores based on well-defined site specific relationship to soil functions. Integration step allows individual indicator score to be combined into single index value. The indicators currently used in SMAF includes soil organic matter, soil aggregation, pH, EC, salinity and SAR, plant available phosphorus, microbial biomass carbon and bulk density.

2.3.3.1 Minimum Data Set

The concept of minimum data set for soil quality assessment was proposed by different researchers since it is impractical to measure all soil properties to assess soil quality. MDS is a small set of indicators needed to characterize soil quality. It is a collection of minimum set of indicators which are required to obtain an overall understanding of the soil under evaluation. MDS is established by identifying key soil attributes that are sensitive to soil functions. It comprises of minimum number of soil processes which are important for a specific soil function (Larson and Pierce, 1991). The properties selected should be easily measurable, measurements should be reproducible and are subjected to some degree of standardization (Carter *et al.,* 1997).

The selection of attributes for minimum dataset can be done based on expert opinion, or using statistical data reduction, or by a combination of both. Soil properties which are relevant for a particular soil function but do not showing much variations in a given study won't be selected for MDS (Doran and Parkin, 1994; Andrews and Carrolls, 2001).

Andrews *et al.* (2002) used principal component analysis is used to create minimum data set and calculate SQI. PCA is regarded as the data reduction tool to select most appropriate indicators to represent SQI. Principal components having eigenvalues greater than one is taken for creating minimum data based on the assumption that PCs receiving high values best represent system attributes. Highly weighted attributes in each PCs will be selected for identifying MDS. Each PCs will be having a certain per cent of variation in the data set. This will be divided by total per cent of variation caused by PCs having eigen values greater than one to obtain weight (Brejda *et al.,* 2000; Andrews *et al.,* 2002; Navas *et al.,* 2011).

2.3.4 Soil quality index

Soil quality indices (SQI) are considered to be the most common methods used for soil quality evaluation due to its flexibility and ease of use for quantification. SQI represent the effects of various soil properties (physical, chemical and ecological) as an index. In weighted additive soil quality index, each soil parameter will be assigned a unitless score ranking from 0 to 1 by using linear scoring functions. Soil parameters will be divided into groups based on three mathematical algorithm functions *viz.,* 'more is better', 'less is better', 'optimum'. The soil parameters will be normalized and the scores will be integrated to single soil quality index in weighted additive method (Andrew *et al.,* 2002).

Amecher *et al.* (2007) introduced a simple additive method for soil quality index calculation. 19 parameters were selected for this method and given threshold values based on expert opinion and literature review. Individual index values are summed up to obtain overall soil quality index.

$\sum$ SQI= $\sum$ individual soil parameter index value

Singh *et al.* (2017) analysed soil quality changes in due to long-term fertilizer application under intensive cropping system in alluvial soils. Minimum data set for the study was selected based on literature review and each of the indicators was divided into four classes based on its suitability. Class I is the most suitable for plant growth whereas class IV is with severe limitations. Marks of 4, 3, 2, and 1 were given to class I, II, III, and IV respectively. Weight was assigned for each parameter based on the existing soil conditions, cropping pattern, and agro-climatic conditions. The sum of all weights is normalized to 100 per cent and index value was worked out. In this method, the maximum value of SQI for soil is 400 and the minimum value 100.

2.4 LAND QUALITY INDEX

The ability of land to produce goods and services that are valued by humans are regarded as land quality and it is influenced by inherent and dynamic properties of soil. Erosion, salinity, water logging, and acidification cause degradation of land resulting in the reduced quality of land in the area. Land quality monitoring is necessity for proper land resources management. Soil organic matter is considered as an indicator of land quality as it influence 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, reduces soil compaction through increasing aeration (Rusco *et al.,* 2001; Rajan *et al.,* 2010).

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

Soil organic carbon (SOC) stocks are regarded the most reliable indicator for monitoring land degradation (Larson and Pierce 1994; Rajan *et al.,* 2010). Kumar *et al.* (2015) studied about the quality of soils of western Karnataka concluded that SOC is a reliable land quality indicator that could corroborate with land use. The better land quality was observed in areas where SOC stock reported higher values with less erosion status.

2.5 GEOGRPHICAL INFORMATION SYSTEM AND SOIL MAPPING

Burrough (1986) defined Geographical Information System as a complete set of tools for collecting, storing, managing, retrieving and transforming spatial data for a certain purpose. It is an information system that is designed to work with geospatial data. GIS has the power to organize complex interrelations among different layers of information through collecting, processing and transforming spatial data and images available through various sources. According to Goodchild (2000), GIS is a computing application which allow the user to create, store, visualize and analyse geographic information. It allows the user to view, analyse and question the data in various ways to show relationships and patterns in the form of maps or charts.

GIS technologies have vital role in soil mapping process to meet the rising demand in the present day agriculture. Soil mapping is of utmost importance as it provides important information regarding the characteristics and condition of the land. Bui *et al.* (1996) assessed soil salinization risk of wet tropics of North Queensland using GIS technology.

GIS technologies can be used in producing soil fertility map of an area, which will help in formulating balanced fertilizer recommendation and to understand the soil fertility status spatially and temporally. There are two levels of a soil map for land use management. The first level consists of an inventory of soil characteristics which will provide information regarding the soil condition on mapping and the second level consists of interpretations of the data. The interpretations play a key role in guiding the farmer on how to wisely manage the land (Binita *et al.,* 2009).

Materials and Methods

3. MATERIALS AND METHODS

The present study entitled "Assessment of soil quality in the post-flood scenario of AEU 4 in Alappuzha District of Kerala and generation of GIS maps" was carried out by collecting surface soil samples from the selected post-flood areas of the AEU 4. Analysis were carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2018-2020. The study was envisaged into following four phases to assess soil quality in the study area after the flood of 2018.

Phase 1 - Survey, collection and characterization of soil

Phase 2 - Setting up of a Minimum Data Set (MDS) for assessment of soil quality (SQ)

Phase 3 - Formulation of Soil Quality Index (SQI)

Phase 4 - Generation of maps using Geographical Information System (GIS)

3.1 SURVEY AND COLLECTION OF SOIL SAMPLES

3.1.1 Details of sampling location

AEU 4 of Alappuzha district (Kuttanad) was one of the areas severely affected by the floods in 2018. Kuttanad, is a special agro-ecological unit which is considered as the 'Rice Bowl of Kerala' having 55,000 ha of paddy fields. Soils of Kuttanad are hydromorphic, often underlain by potential acid sulphate sediments and unique hydrological conditions that characterize the unit (KAU, 2016). The present study was conducted in representative panchayats to assess the impact of flood on soil quality of the region. The flood affected panchayats for the study were identified and selected with the help of the officials from the Department of Agriculture, Government of Kerala.

3.1.2 Collection of samples

A survey was conducted in the flood affected areas of the AEU using pre designed questionnaire (Appendix I) and the details regarding the crops grown, cropping system adopted and nutrient management practices were collected (Appendix II). Geo-referenced surface soil samples were collected from the seventeen selected panchayats of AEU 4 in

Alappuzha district during April 2019 from the different locations of study area (Fig. 1). From each sampling sites, soil samples were collected to a depth of 0-20 cm and the collected samples were packed and labelled in polythene covers (Plates 1-4). Geo Positioning System (GPS) was used for collecting the geographical coordinates of the sampling locations. Details of sampling locations with geo-coordinates are represented in Table 1.

Table 1. Location details

Sl. No.	Panchayat/Municipality	No. of samples	Sampling points	Latitude	Longitude
1	Alappuzha Municipality (Ponga, Chungam)	6	1	9.50862	76.3467
			2	9.510511	76.36684
			3	9.471734	76.33763
			4	9.503616	76.36174
			5	9.490003	76.34897
			6	9.470809	76.35295
2	Kainakary	9	7	9.449448	76.38922
			8	9.473261	76.37259
			9	9.51717	76.39973
			10	9.489283	76.37863
			11	9.518402	76.38963
			12	9.490603	76.37661
			13	9.480082	76.39127
			14	9.505508	76.38662
			15	9.463095	76.38782
3	Champakulam	7	16	9.436702	76.44143
			17	9.433372	76.41263
			18	9.426783	76.41765
			19	9.410891	76.42009

Table 1 continued

Sl. No.	Panchayat/Municipality	No. of samples	Sampling points	Latitude	Longitude
			20	9.405066	76.4267
			21	9.39768	76.42891
			22	9.421192	76.4267
4	Nedumudi	3	23	9.448094	76.37202
			24	9.429445	76.38247
			25	9.406751	76.39569
5	Pulinkunnu	8	26	9.51693	76.42275
			27	9.461512	76.42556
			28	9.486804	76.41653
			29	9.501511	76.42917
			30	9.504659	76.41345
			31	9.446391	76.4216
			32	9.452958	76.43416
			33	9.472728	76.41686
6	Veliyanad	3	34	9.480367	76.44579
			35	9.457437	76.45761
			36	9.441512	76.47939
7	Neelamperoor	4	37	9.475245	76.47484
			38	9.469747	76.48929
			39	9.488855	76.49352
			40	9.495585	76.47892
8	Kavalam	4	41	9.54648	76.45057
			42	9.523441	76.46438
			43	9.529992	76.44897
			44	9.50461	76.45984

Table 1 continued

Sl. No.	Panchayat/Municipality	No. of samples	Sampling points	Latitude	Longitude
9	Muttar	2	45	9.398399	76.49912
			46	9.401884	76.48268
10	Ramankary	6	47	9.401251	76.45638
			48	9.418526	76.45524
			49	9.416093	76.49218
			50	9.391756	76.46505
			51	9.422737	76.47176
			52	9.4344	76.45634
11	Ambalappuzha South	4	53	9.385457	76.36238
			54	9.390167	76.37535
			55	9.381153	76.3888
			56	9.371238	76.39178
12	Purakkad	3	57	9.321037	76.38895
			58	9.342167	76.38338
			59	9.366096	76.37073
13	Thakazhi	3	60	9.3581	76.40952
			61	9.360696	76.43162
			62	9.37797	76.41906
14	Edathua	4	63	9.361476	76.46806
			64	9.380607	76.44879
			65	9.371898	76.45892
			66	9.349478	76.47057
15	Thalavadi	3	67	9.368405	76.50236
			68	9.380654	76.49197
			69	9.355018	76.49433

Table 1 continued

Sl. No.	Panchayat/Municipality	No. of samples	Sampling points	Latitude	Longitude
16	Pandanad	4	70	9.330127	76.55831
			71	9.323737	76.57728
			72	9.328162	76.56646
			73	9.323236	76.58899
17	Puliyur	2	74	9.283157	76.57335
			75	9.30368	76.58912

3.1.3 Weather data of the area

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

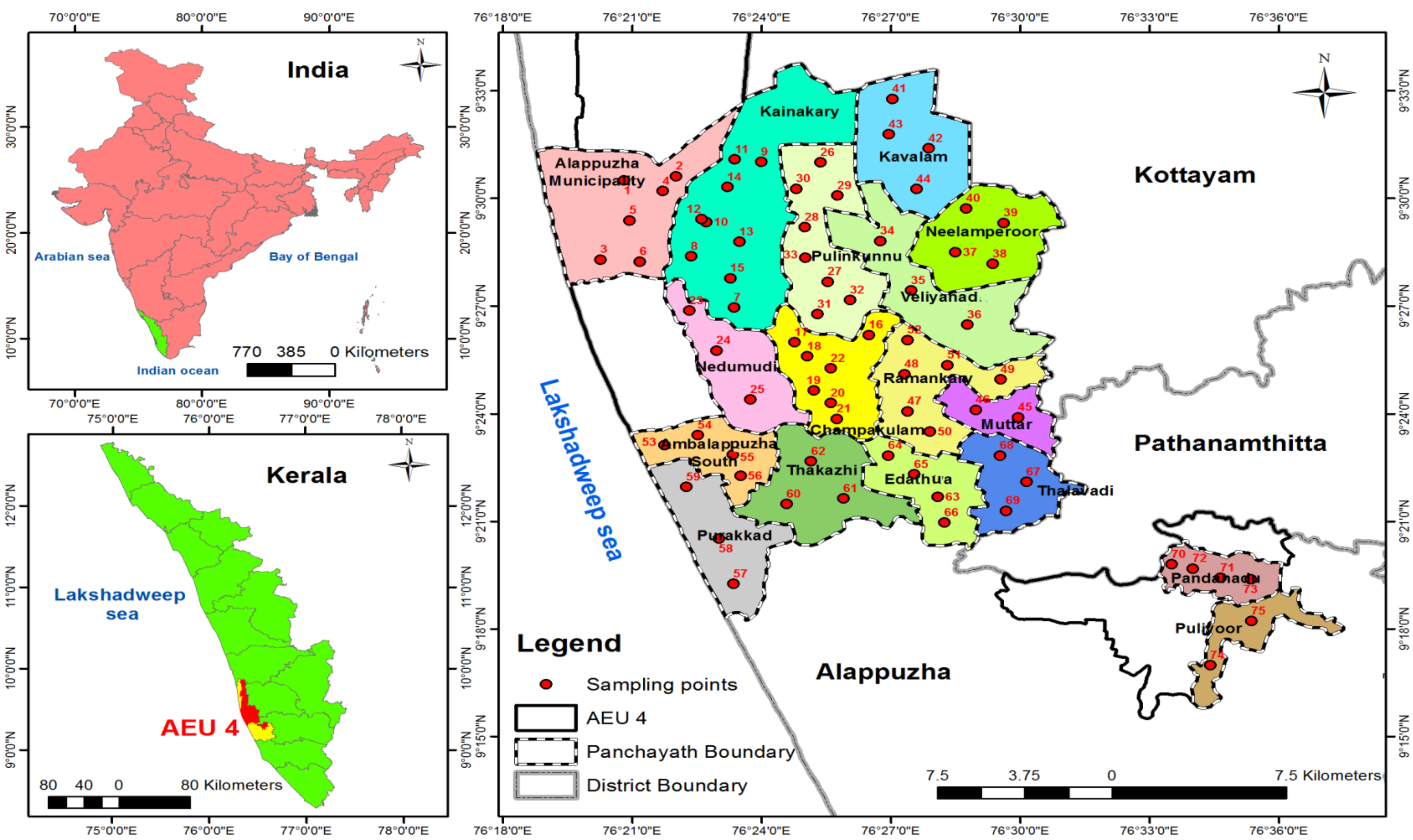

Fig. 1 Location map of sampling points in AEU 4 of Alappuzha district

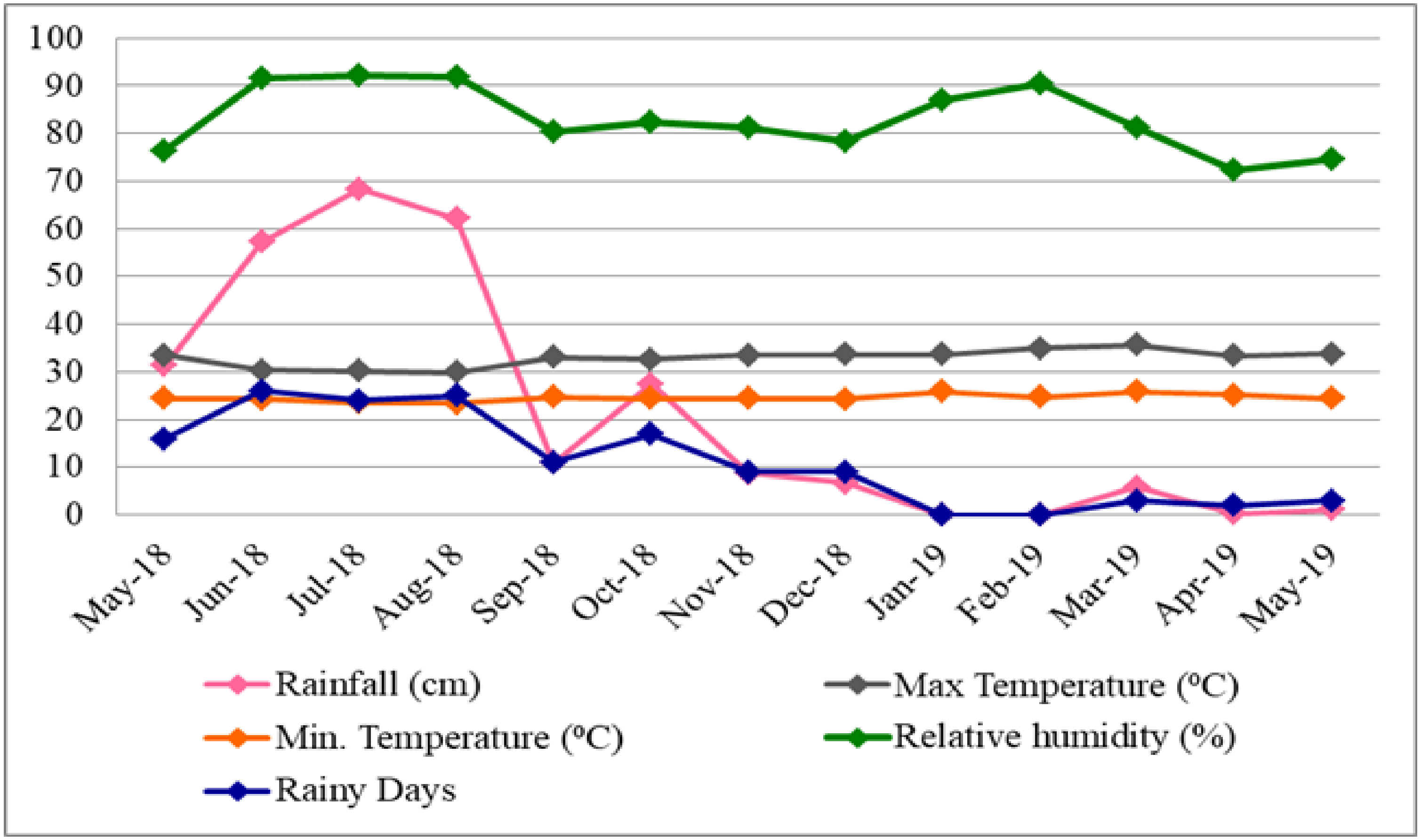

Fig. 2 Monthly mean of weather parameters in AEU 4 of Alappuzha district during May 2018 to May 2019

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

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

On comparison of the average rainfall of the previous ten years (2008-2017) with that of the year 2018, a positive deviation was observed during May, June, July and August (Table 2). 300.65 mm and 324.42 mm increase in average rainfall occurred in July and August respectively. Also, a positive deviation was observed in the number of rainy days in the months of May, June, July, August, October and December 2018 from that of the average number of rainy days of the previous ten years.

3.2 CHARACTERIZATION OF SOILS

Soil samples were dried under shade, crushed with wooden mallet. Air-dried soil samples were passed through 2 mm sieve (stainless steel) and stored for further analysis. Collected soil samples were analysed for physical, chemical and biological attributes using the standard analytical procedures described below.

3.2.1 Physical and Chemical Characterization

Table 3. Standard analytical methods followed in the soil analysis

SI. No	Parameter	Method	Reference
Physical properties			
1	Bulk density	Undisturbed core sample	Gupta and Dakshinamurthy (1980)
2	Particle density	Pycnometer method	Black *et al.* (1965)
3	Porosity	Calculation using bulk density and particle density	Danielson and Sutherland (1986)
4	Soil texture	Bouyoucos hydrometer method	Bouyoucos (1962)
5	Water holding capacity	Core method	Gupta and Dakshinamurthy (1980)
6	Moisture content	Gravimetric method	Gardner (1986)
7	Aggregate stability	Yoder’s wet sieving method	Yoder (1936)
Chemical properties			
8	pH	pH meter (1:2.5 soil water ratio)	Jackson (1973)
9	EC	Conductivity meter (1:2.5 soil water ratio)	Jackson (1973)

Table 3 continued

SI. No	Parameter	Method	Reference
10	Organic carbon	Walkley and Black rapid titration method	Walkley and Black (1934)
11	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
12	Available P	Bray No. 1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
13	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
14	Exchangeable Ca and Mg	Versanate titration method	Hesse (1971)
15	Available S	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)
16	Available Boron	Hot water extraction and spectrophotometry (Azomethane-H method)	Gupta (1967)

3.2.2 Biological parameter

3.2.2.1 *Acid phosphatase activity*

The acid phosphatase activity in soil was determined by the procedure described by Eivazi and Tabatabai (1977). One gram soil was weighed and transferred to each 50 ml volumetric flask where 0.2 ml toluene, 4 ml modified universal buffer (pH-6.5) and 1 ml p-nitrophenyl phosphate solution were added and incubated at 37 ^{o}C for one hour. After the incubation, 0.5 *M* $CaCl_2$ (1 ml) and 0.05 *M* NaOH (1 ml) were added. The contents were gently swirled and filtered through Whatman No.2 filter paper and the intensity of the yellow colour developed in the filtrate was read using Spectrophotometer at a wavelength of 420 nm. The equipment was standardized with different concentrations of one per cent solution of p-nitrophenol. The results were expressed in terms of p-nitrophenol released g^{-1} of soil h^{-1} in micrograms.

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

Minimum data set (MDS) for soil quality assessment selected by carrying out Principal Component Analysis. Principal component analysis (PCA) is a technique used to emphasize variation and bring out strong patterns in a dataset. Principal components having eigenvalues greater than one was used as a criteria for the selection of MDS. It is based on the assumption that the principal components (PCs) having eigenvalues greater than one is best for representing the system attributes. For a particular PC, each variable receives a weight that represents its contribution to the PC. The highly weighted variables (within the 10 per cent of the highest factor loading) from each PC is retained for the MDS. If more than one variable retained in a PC, then linear correlation between the retained variables will be workout using OPSTAT software to select the variables for MDS. If the highly weighted variables are not correlated (<0.60), then each variable will be considered important and retained in MDS. Among the well correlated variables in the PC, the variables with highest sum of correlation coefficients were chosen for the MDS (Andrews *et al.*, 2002).

3.4 FORMULATION OF SOIL QUALITY INDEX.

The soil quality evaluation was done as per the procedure described by Larson and Pierce in 1994. Appropriate scores will be assigned to the indicators selected for MDS. The status of each attribute was categorized into four classes *viz*., Class-I (very good status), Class-II (good status), Class-III (poor status) and Class-IV (very poor) and marks of 4, 3, 2 and 1 were assigned to the classes respectively (Kundu *et al.*, 2012; Mukherjee and Lal, 2014).

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

$$SQI = \sum W_i \times M_i$$

Where W_i is weight of the indicators and M_i is the marks of the indicator classes.

The relative soil quality index (RSQI) was worked out using the concept of Karlen and Stott (1994). RSQI of each sampling location was rated as poor (RSQI < 50 per cent), medium (RSQI 50-70 per cent) and good (RSQI > 70 per cent

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

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

3.5 NUTRIENT INDEX

Nutrient index (N.I) for organic carbon content, available nitrogen, phosphorus and potassium were calculated according to the procedure given by Ramamoorthy and Bajaj (1969).

$$\text{Nutrient Index (N.I.)} = \frac{1 \times N_L + 2 \times N_M + 3 \times N_H}{N_T}$$

N_L : Indicates number of samples falling in low class of nutrient status

N_M : Indicates number of samples falling in medium class of nutrient status

N_H : Indicates number of samples falling in high class of nutrient status

N_T : Indicates total number of samples analysed for a given area.

Interpretation of the different values of Soil Nutrient Index are given in Table 4.

Table 4. Ratings of Nutrient index value for nutrients

SI. No.	Nutrient Index	Value	Interpretation
1	Low	<1.67	Low fertility Status of the area
2	Medium	1.67-2.33	Medium fertility Status of the area
3	High	>2.33	High fertility Status of the area

3.6 LAND QUALITY INDEX

Land quality index was calculated based on soil organic carbon stock as per the criteria stated by Shalimadevi (2006) (Table 5).

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

Table 5. Land quality index rating

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 MAPS USING GIS

GIS based thematic maps were generated using ArcGIS software. Various thematic maps for sampling location, soil texture, soil pH, organic carbon, available macronutrients, calcium, magnesium, sulphur, boron, soil quality index, nutrient index and land quality index were prepared using ArcGIS software version 10.3.

The interpolation tool used for the current study is inverse distance weighted interpolation (IDW). It is a deterministic method and the assigned values for unknown points are calculated with the weighted average of values available at the known points. It is done based on the assumption that makes the assumption that the things that are close to one another are more alike than those that are farther apart (Ogbozige *et al.*, 2018). The soil analysis data along with the respective geo coordinates were entered in MS excel, converted into comma separated value (CSV) file and imported into the ArcGIS software. The shape file with the boundaries of study area were imported into the ArcGIS software. IDW tool was selected and longitude, latitude and soil attributes were assigned in x, y and z axis respectively and boundaries of the sampled panchayats were taken as the processing extent in the IDW dialog box. The number of sampling points were also entered and the data was interpolated. The output map obtained for each parameter was classified manually based on the standard ratings and different colours were allotted for each class.

3.8 STATISTICAL ANALYSIS OF THE DATA

Correlations between physical, chemical and biological parameters were calculated using OPSTAT software in terms of Pearson's correlation coefficient (Panse and Sukhatme, 1978).

Plate 1. Sampling location (rice field in Kuttanad)

Plate 2. Soil sampling from farmer’s field

Plate 3. Quartering of soil sample

Plate 4. Sealed and labeled soil sample for analysis

Results

4. RESULTS

The present study entitled "Assessment of soil quality in the post-flood scenario of AEU 4 in Alappuzha District of Kerala and generation of GIS maps" was carried out at the College of Agriculture, Vellayani during the period from 2018 to 2020. The study was envisaged for assessment of quality of post flood soils of AEU 4 of Alappuzha district through the physical, chemical and biological characterization of the soil. The experimental results generated during the course of the investigation are presented in this chapter.

4.1 DETAILS OF FIELD SURVEY CONDUCTED IN AEU 4 OF ALAPPUZHA DISTRICT

A preliminary survey was conducted in the AEU 4 with the help of questionnaire and with the interaction with the incumbents of the locality, revealed that Kuttanad was one of the worsely affected areas in Kerala during the floods in 2018. The occurrence of flood in Kuttanad was three times during the period from July to August of 2018. Major parts of the area were submerged during the entire phase of flood and various roads and bunds were broken in many parts of Kuttanad. Most of the people from Kuttanad taluk were evacuated and shifted to flood rehabilitation camps during these months. Water level rose to about 5 feet in many parts and serious deterioration of both households and agricultural land was reported. Champakulam, Veliyanad, Ambalappuzha and Chenganur were the highly flood affected blocks in AEU 4 of Alappuzha district.

With respect to the cropping details, it is noticed that rice is the major crop grown in Kuttanad and hence the name "Rice Bowl of Kerala". In many of the paddy fields, rice crop was about 45 to 75 days old when the flood hit Kuttanad and complete loss of the standing crop was reported. An estimated loss of ten thousand to twenty five thousand rupees per acre was incurred for many paddy farmers. Majority of the farmers follow conventional method of farming practices in the paddy fields (Table 6).

The practice of Integrated Nutrient Management (INM) was adopted by 20 per cent of farmers, while 80 per cent of farmers follow conventional method of cultivation in

Kuttanad. Also the use of biofertilizers and biopesticides in the agricultural fields was not reported. Since rice is grown collectively in padashekharams and to maximize the yield, farmers resort to the use of chemical fertilizers. Dolomite and lime were commonly used as liming material to mitigate acidity problems. Fertilizers such as Urea, Factomfos and Muriate of Potash were used predominantly as nutrient sources for paddy cultivation. About 86.67 per cent of the farmers had a holding size less than 1 ha and belonged to the category of marginal farmers and the rest were small farmers (13.33 per cent).

Table 6. Details of field survey conducted in AEU 4 of Alappuzha district

Particulars	No. of farmers	Percentage
Crops		
1. Paddy	75	100
Nutrient management		
1. INM	15	20
2. Organic	0	0
3. Conventional	60	80
Size of holding		
1. <1 ha	65	86.67
2. 1-2 ha	10	13.33

4.2 CHARACTERIZATION OF SOIL SAMPLES

4.2.1 Physical attributes

Soil samples were analyzed for various physical properties namely bulk density, particle density, porosity, texture, water holding capacity, soil moisture content and aggregate stability**.** The results pertaining to the aforesaid attributes are furnished below in the subsequent paragraphs.

4.2.1.1 Bulk density

The mean values for bulk density of the post flood soils of AEU 4 of Alappuzha district varied from 0.66 Mg m^{-3} to 1.43 Mg m^{-3} (Table 7). The lowest mean value for bulk density was reported in Neelamperoor (0.66 Mg m^{-3}) and the highest mean value was recorded in Pandanad (1.43 Mg m^{-3}) which was followed by Puliyur (1.41 Mg m^{-3}) and Alappuzha Municipality (1.35 Mg m^{-3}).

4.2.1.2 Particle density

From the data generated, it was observed that particle density of all the samples analyzed were lower than 2.65 Mg m^{-3} (Table 7). The mean values for particle density of the study area ranged from 1.67 to 2.31 Mg m^{-3}. The highest mean value for particle density was recorded in Alappuzha Municipality (2.31 Mg m^{-3}) which is followed by Thakazhi (2.23 Mg m^{-3}), Puliyur (2.13 Mg m^{-3}) and Champakulam (2.11 Mg m^{-3}). The lowest mean value for particle density was recorded in Kavalam (1.67 Mg m^{-3}).

4.2.1.3 Porosity

It is indicated in Table 7 that mean values for porosity of study area was in the range of 28.9 to 64.7 per cent. The highest mean value for porosity was recorded from Neelamperoor panchayat (64.7 per cent) followed by Edathua (58.6 per cent) and the lowest was reported in Pandanad panchayat (28.9 per cent).

Table 7. Bulk density, particle density and porosity in post flood soils of AEU 4 in Alappuzha district

Panchayat/Municipality	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	1.35 ± 0.23	1.13-1.58	2.31 ± 0.34	1.99-2.66	40.4 ± 15.1	30.4-57.7
Kainakary	1.02 ± 0.13	0.89-1.25	1.91 ± 0.19	1.66-2.20	45.9 ± 11.3	24.2-53.8
Champakulam	1.06 ± 0.09	0.99-1.18	2.11 ± 0.42	1.74-2.76	47.9 ± 12.1	34.7-64.1
Nedumudi	1.10 ± 0.04	1.07-1.12	1.99 ± 0.01	1.98-1.99	44.8 ± 1.80	43.5-46.1
Pulinkunnu	0.98 ± 0.20	0.74-1.21	1.85 ± 0.14	1.69-2.01	47.3 ± 7.29	39.8-56.1
Veliyanad	1.07 ± 0.41	0.79-1.36	2.08 ± 0.39	1.80-2.36	49.3 ± 10.1	42.2-56.4
Neelamperoor	0.66 ± 0.17	0.54-0.79	1.87 ± 0.13	1.78-1.96	64.7 ± 6.76	60.0-69.6
Kavalam	0.94 ± 0.09	0.83-1.01	1.67 ± 0.14	1.51-1.75	43.5 ± 8.47	35.7-52.5
Muttar	0.82 ± 0.06	0.78-0.86	1.83 ± 0.08	1.78-1.89	55.2 ± 1.32	54.3-56.2
Ramankary	0.87 ± 0.32	0.50-1.12	1.86 ± 0.06	1.79-1.89	52.9 ± 18.5	37.3-73.4
Ambalappuzha South	1.23 ± 0.32	0.99-1.47	1.95 ± 0.45	1.48-2.37	36.1 ± 11.3	26.7-48.7
Purakkad	1.07 ± 0.07	1.03-1.12	1.90 ± 0.09	1.83-1.97	43.5 ± 0.80	42.9-44.1
Thakazhi	0.99 ± 0.12	0.85-1.09	2.23 ± 0.66	1.71-2.97	53.8 ± 10.5	45.5-65.7
Edathua	0.80 ± 0.24	0.52-0.97	1.99 ± 0.18	1.81-2.16	58.6 ± 14.8	49.0-75.7
Thalavadi	0.92 ± 0.06	0.88-0.96	2.04 ± 0.23	1.88-2.21	54.4 ± 7.89	48.8-60.0
Pandanad	1.43 ± 0.02	1.40-1.45	2.01 ± 0.03	1.98-2.05	28.9 ± 1.91	26.7-30.1
Puliyur	1.41 ± 0.20	1.28-1.56	2.13 ± 0.08	2.08-2.20	33.6 ± 6.90	28.7-38.4
AEU 4	1.04 ± 0.25	0.50-1.88	1.98 ± 0.26	1.48-2.97	47.2 ± 12.2	24.2-73.4

4.2.1.4 Soil texture

The soil texture of the study area was studied and particle size distributions of soil samples *viz.,* sand, silt, clay contents were calculated for the study area. The mean values for soil separates of each panchayats are presented in the Table 8.

The mean values of sand content in the study area varied between 22.7 and 73.5 per cent. The highest mean value of sand content was observed for Ambalappuzha South panchayat (73.5 per cent) while the lowest in Neelamperoor (22.7 per cent).

The mean values of silt content of the samples from the study area varied from 8.33 to 45 per cent. The highest mean value for silt content was recorded in Veliyanad panchayat (45 per cent) while the lowest was reported in Alappuzha Municipality (8.33 per cent).

With respect to the clay content, the mean values in the post flood soils of AEU 4 of Alappuzha district varied between 20.6 and 42.3 per cent. The highest mean value was recorded for Neelamperoor panchayat (42.3 per cent) and the lowest mean was noticed in Alappuzha Municipality (20.6 per cent).

The major soil textural classes observed in the study area were sandy clay loam, sandy loam, loam, clay loam, clay, sandy clay, silty clay and silty clay loam. Of these sandy clay loam was the most predominant soil textural class observed in Champakulam, Nedumudi, Kavalam, Ramankary, Ambalappuzha South, Pandanad and Puliyur. Muttar, Thalavadi, Edathua, Neelamperoor and Veliyanad panchayats were dominated by clay loam. Sandy loam was the major textural class noticed in Alappuzha Municipality and Kainakary panchayat. Apart from these textural classes, loam and clay were observed in some parts of Thakazhi, Edathua and Purakkad.

Table 8. Sand, silt and clay content in the post flood soils of AEU 4 in Alappuzha district, per cent.

Panchayat/Municipality	Sand (%)		Silt (%)		Clay (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	71.8 ± 1.44	70.2-75.2	8.33 ± 1.44	7.50-10.0	20.6 ± 1.44	19.8-22.3
Kainakary	56.1 ± 11.1	35.2-65.2	20.0 ± 8.94	10.0-35.0	23.9 ± 4.92	19.8-29.8
Champakulam	50.2 ± 24.7	10.2-75.2	25.5 ± 21.7	5.00-60.0	24.3 ± 3.71	19.8-29.8
Nedumudi	45.2 ± 35.4	20.2-70.2	32.5 ± 38.9	5.00-60.0	22.3 ± 3.54	19.8-24.8
Pulinkunnu	45.7 ± 17.5	20.2-60.2	24.5 ± 6.71	15.0-30.0	29.8 ± 12.7	19.8-49.8
Veliyanad	27.7 ± 10.6	20.2-35.2	45.0 ± 3.54	45.0-50.0	27.3 ± 10.6	19.8-34.8
Neelamperoor	22.7 ± 3.53	20.2-25.2	35.0 ± 7.07	30.0-40.0	42.3 ± 3.54	39.8-44.8
Kavalam	33.5 ± 12.6	20.2-45.2	28.3 ± 2.89	25.0-30.0	38.1 ± 10.4	29.8-49.8
Muttar	37.2 ± 2.83	35.2-39.2	38.8 ± 1.91	37.5-40.2	28.2 ± 1.20	27.3-29.0
Ramankary	58.5 ± 7.64	50.2-65.2	13.3 ± 5.77	10.0-20.0	28.1 ± 2.89	24.8-29.8
Ambalappuzha South	73.5 ± 2.89	70.2-75.2	8.75 ± 1.44	7.60-9.50	20.6 ± 4.44	19.8-22.3
Purakkad	45.2 ± 21.2	30.2-60.2	22.5 ± 3.54	20.0-25.0	32.3 ± 17.7	19.8-44.8
Thakazhi	35.2 ± 5.00	30.2-40.2	39.2 ± 8.78	30.0-47.5	25.6 ± 8.04	19.8-34.8
Edathua	41.9 ± 10.4	30.2-45.2	26.7 ± 15.3	10.0-40.0	31.4 ± 12.6	19.8-44.8
Thalavadi	40.2 ± 7.07	35.2-45.2	32.5 ± 3.54	30.0-35.0	27.3 ± 10.6	19.8-34.8
Pandanad	45.2 ± 8.66	35.2-50.2	20.8 ± 1.44	20.0-22.5	33.9 ± 7.22	29.8-42.3
Puliyur	52.7 ± 10.6	45.2-60.2	17.5 ± 10.6	10.0-25.0	31.1 ± 1.77	29.8-32.3
AEU 4	48.2 ± 18.7	20.2-75.2	23.4 ± 13.8	5.00-60.0	28.3 ± 8.51	19.8-49.8

4.2.1.5 Depth of silt/clay/sand deposition

Deposits of silt and clay ranging from 3 to 20 cm were reported in all the selected panchayats for the present study. The intensity of deposition was more in places nearer to canals and river banks. Kainakary, Champakulam, Pulinkunnu, Kavalam, Neelamperoor, Muttar, Ramankary, Veliyanad, Thakazhi, Edathua, Pandanad, Puliyur were highly affected by silt deposition. In Alappuzha Municipality and Ambalappuzha South only trace amount of deposition was reported. As per the survey and the information collected from the respondents the deposition of silt and clay up to 2-3 feet was observed after the flood in household and paddy fields .From the survey it is also noted that tillage operations were carried out before raising a crop in order to loosen the deposits.

4.2.1.6 Water holding capacity

The mean values for water holding capacity of the soils from different flood affected panchayats ranged between 32 and 58.5 per cent (Table 9). The highest value for water holding capacity was recorded in Thakazhi (58.5 per cent) which is followed by Neelamperoor (57.1 per cent), Veliyanad (56.3 per cent) and Kainakary (53.9 per cent). The lowest value for water holding capacity was recorded from Pandanad (32.0 per cent).

4.2.1.7 Soil moisture content

The mean values for moisture content of the study area varied from 16.4 to 52.2 per cent (Table 9). The highest value was recorded in Veliyanad (52.2 per cent), followed by Neelamperoor (43.8 per cent) and lowest value was recorded in Pandanad (16.4 per cent).

Table 9. Water holding capacity and moisture content of post flood soils of AEU 4 in Alappuzha district, per cent.

Panchayat/Municipality	Water holding capacity (%)		Moisture content (%)	
	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	37.1 ± 3.91	32.7-40.2	21.5 ± 8.55	14.6-31.1
Kainakary	53.9 ± 9.89	41.5-65.6	39.0 ± 9.09	23.6-50.8
Champakulam	49.4 ± 3.20	46.8-53.4	40.9 ± 2.79	37.7-45.4
Nedumudi	48.6 ± 3.80	45.9-51.3	35.1 ± 16.1	23.7-46.5
Pulinkunnu	46.8 ± 4.44	42.8-53.8	38.7 ± 3.12	34.6-43.3
Veliyanad	56.3 ± 1.36	55.3-57.2	52.2 ± 3.52	49.7-54.7
Neelamperoor	57.1 ± 1.19	56.3-57.9	43.8 ± 5.61	39.8-47.8
Kavalam	45.9 ± 4.04	42.6-50.5	41.9 ± 4.85	37.1-46.8
Muttar	44.7 ± 0.67	44.3-45.2	38.7 ± 1.78	37.5-40.0
Ramankary	52.9 ± 12.3	38.8-61.4	43.7 ± 9.33	32.9-49.8
Ambalappuzha South	36.9 ± 10.5	28.1-48.6	17.1 ± 2.82	14.4-20.0
Purakkad	45.2 ± 2.43	43.5-46.9	24.5 ± 3.57	22.0-27.1
Thakazhi	58.5 ± 9.49	48.8-67.7	41.9 ± 3.35	38.2-44.6
Edathua	50.9 ± 16.8	31.8-63.5	39.1 ± 15.0	23.1-52.9
Thalavadi	51.6 ± 17.7	39.0-64.1	20.4 ± 0.52	20.1-20.8
Pandanad	32.0 ± 2.11	29.8-34.1	16.4 ± 5.63	10.2-21.2
Puliyur	34.4 ± 12.1	25.8-43.9	24.7 ± 15.6	13.7-35.8
AEU 4	47.5 ± 9.90	25.8-67.7	35.1 ± 11.9	10.2-54.7

4.2.1.8 Aggregate stability

Aggregate stability of samples from the 17 panchayats were analyzed and are presented in Table 10. The mean values for water stable aggregates ranged from 57.2 to 81.1 per cent. Purakkad reported the highest mean value for water stable aggregates with a value of 81.1 per cent and while Muttar panchayat reported the lowest value of 57.2 per cent. Mean weight diameter of the aggregates of selected panchayats ranged from 1.17 to 2.15 mm. The highest value for mean weight diameter was recorded in Purakkad (2.15 mm) and the lowest was reported in samples from Muttar (1.17 mm).

Table 10. WSA and MWD of post flood soils of AEU 4 of Alappuzha district

Panchayat/Municipality	WSA (%)		MWD (mm)	
	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	77.1 ± 3.16	74.5-83.2	1.47 ± 0.10	1.32-1.60
Kainakary	68.9 ± 12.8	47.1-90.3	1.58 ± 0.41	0.88-2.22
Champakulam	67.1 ± 8.44	53.1-76.0	1.44 ± 0.19	1.16-1.69
Nedumudi	65.7 ± 18.0	47.1-83.0	1.43 ± 0.51	0.95-1.97
Pulinkunnu	70.0 ± 12.6	52.9-92.2	1.68 ± 0.34	1.10-2.23
Veliyanad	75.6 ± 7.07	69.8-83.5	1.82 ± 0.31	1.82-2.44
Neelamperoor	74.1 ± 2.41	70.6-75.7	1.95 ± 0.20	1.77-2.19
Kavalam	68.4 ± 5.43	62.9-73.3	1.77 ± 0.34	1.31-2.15
Muttar	57.2 ± 2.83	55.2-59.2	1.17 ± 0.18	1.04-1.30
Ramankary	66.2 ± 5.83	59.0-75.7	1.46 ± 0.26	1.08-1.82
Ambalappuzha South	70.2 ± 7.32	61.0-78.8	1.41 ± 0.21	1.16-1.68
Purakkad	81.1 ± 4.88	77.5-86.7	2.15 ± 0.24	1.88-2.33
Thakazhi	63.5 ± 8.53	54.0-70.5	1.23 ± 0.33	1.02-1.62
Edathua	62.6 ± 9.88	53.8-74.3	1.57 ± 0.11	1.45-1.68
Thalavadi	71.9 ± 2.72	69.1-74.6	1.45 ± 0.20	1.25-1.65
Pandanad	64.6 ± 9.24	55.9-77.2	1.21 ± 0.36	0.99-1.75
Puliyur	74.2 ± 8.50	68.2-80.2	1.75 ± 0.10	1.68-1.82
AEU 4	69.4 ± 9.60	47.1-92.2	1.60 ± 0.40	0.88-2.33

4.2.2. Chemical attributes

The soil samples were analyzed in the laboratory for chemical parameters *viz.*, pH, EC, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and boron by following various standard procedures. The results obtained are presented below.

4.2.2.1 Soil pH

From the Table 11 it is observed that all the soils are acidic in reaction. Mean values for soil pH of selected panchayats ranged from 3.54 to 4.79. Lowest mean value for soil pH recorded in Neelamperoor (3.54) and highest in Puliyur (4.79). All the samples show pH below 4.5 except Thalavadi and Puliyur. Mean values for pH of Thalavadi and Puliyur comes under ‘very strongly acidic’ range (4.5-5.0) while mean values of all others belonged to extremely acidic range (3.5-4.4). Comparing all the samples, the least value for soil pH was recorded in Edathua which comes under ultra acidic range and the value recorded was 3.14. Highest value for soil pH was recorded in Champakulam (5.21) and belonged to strongly acidic range. Most of the analyzed samples belonged to extremely acidic range.

4.2.2.2 Electrical conductivity

From the perusal of the data in Table 11, it is observed that all the soils from 17 flood affected panchayats belonged to non-saline category (<2 dS m^{-1}). The mean values for EC of soils in the study area ranged from 0.36 to 0.88 dS m^{-1}. The highest mean value for EC was recorded in the soil samples from Purakkad (0.88 dS m^{-1}) followed by Edathua (0.78 dS m^{-1}) and Thalavadi (0.77 dS m^{-1}) and the lowest value in Puliyur (0.36 dS m^{-1}).

4.2.2.3 Organic carbon

The organic carbon content in all the panchayats were high and ranged from 1.88 to 5.39 per cent (Table 11). The highest mean value for organic carbon was recorded in Neelamperoor (5.39 per cent) which is followed by Purakkad (5.30 per cent), Veliyanad

(4.42 per cent), Edathua (4.12 per cent) and Kavalam (4.04 per cent). Lowest value of mean value for organic carbon was recorded in Alappuzha Municipality.

Table 11. Soil pH, EC and organic carbon content in the post flood soils of AEU 4 in Alappuzha district

Panchayat/Municipality	pH		EC (dS m^{-1})		Organic Carbon (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	4.24 ± 0.19	3.95-4.48	0.70 ± 0.09	0.56-0.81	1.88 ± 0.64	0.84-2.70
Kainakary	4.35 ± 0.37	3.58-4.81	0.62 ± 0.13	0.44-0.81	2.48 ± 0.41	1.82-3.03
Champakulam	4.33 ± 0.50	3.95-5.21	0.66 ± 0.16	0.40-0.90	2.42 ± 0.96	1.29-4.26
Nedumudi	4.25 ± 0.11	4.17-4.37	0.60 ± 0.14	0.44-0.72	2.21 ± 0.26	1.95-2.46
Pulinkunnu	4.12 ± 0.18	3.92-4.40	0.59 ± 0.17	0.39-0.88	3.12 ± 0.72	2.06-4.20
Veliyanad	4.11 ± 0.32	3.78-4.41	0.55 ± 0.12	0.43-0.68	4.42 ± 0.38	4.08-4.83
Neelamperoor	3.54 ± 0.06	3.48-3.60	0.59 ± 0.11	0.47-0.74	5.39 ± 0.30	4.98-5.67
Kavalam	3.88 ± 0.25	3.54-4.11	0.60 ± 0.05	0.56-0.67	4.04 ± 1.12	2.81-5.46
Muttar	4.33 ± 0.22	4.17-4.48	0.67±0.056	0.63-0.71	3.23 ± 0.65	2.78-3.69
Ramankary	4.05 ± 0.30	3.50-4.33	0.71 ± 0.11	0.58-0.85	3.06 ± 0.97	2.30-4.47
Ambalappuzha South	3.55 ± 0.20	3.25-3.69	0.62 ± 0.13	0.45-0.77	2.10 ± 0.61	1.32-2.82
Purakkad	3.71 ± 0.02	3.68-3.72	0.88 ± 0.90	0.81-0.98	5.30 ± 0.32	4.95-5.58
Thakazhi	3.85 ± 0.29	3.62-4.17	0.73 ± 0.16	0.56-0.87	3.56 ± 1.07	2.64-4.74
Edathua	4.00 ± 0.68	3.14-4.66	0.78 ± 0.12	0.60-0.89	4.12 ± 0.14	3.96-4.29
Thalavadi	4.56 ± 0.26	4.30-4.81	0.77 ± 0.25	0.50-1.00	2.35 ± 1.08	1.44-3.54
Pandanad	4.32 ± 0.82	3.35-5.12	0.57 ± 0.28	0.30-0.95	2.60 ± 0.83	1.92-3.63
Puliyur	4.79 ± 0.11	4.71-4.86	0.36 ± 0.18	0.23-0.49	1.89 ± 0.38	1.56-2.21
AEU 4	4.11 ± 0.43	3.14-5.21	0.64 ± 0.20	0.23-1.00	3.11 ± 1.18	0.84-5.67

4.2.2.4. Available nitrogen

From the data presented in Table 12, it is observed that a wide variation existed with respect to available nitrogen status in the sampling sites. The mean values for available nitrogen ranged from 188 kg ha^{-1} to 602 kg ha^{-1}. The highest mean value was reported in soils from Veliyanad (602 kg ha^{-1}) followed by Neelamperoor (545 kg ha^{-1}) and the lowest in Puliyur (188 kg ha^{-1}).

4.2.2.5 Available phosphorus

From the data presented in Table 12, it is inferred that the available phosphorus content in the study area showed wide variation. The mean values for available phosphorus in the study area varied from 5.79 kg ha^{-1} to 24.2 kg ha^{-1}. The highest mean value for available phosphorus was recorded from Ambalappuzha South panchayat (24.2 kg ha^{-1}) followed by Alappuzha Municipality (22.9 kg ha^{-1}) and Kainakary (22.3 kg ha^{-1}) while the lowest value was observed in Muttar (5.79 kg ha^{-1}).

4.2.2.6 Available potassium

The mean values for available potassium ranged from 252 kg ha^{-1} to 672 kg ha^{-1} (Table 12). The highest mean value for available potassium was recorded from Purakkad (672 kg ha^{-1}) followed by Kainakary (662 kg ha^{-1}) and lowest was recorded from Puliyur which was 252 kg ha^{-1}.

Table 12. Available N, P and K status in the post flood soils of AEU 4 in Alappuzha district, kg ha^{-1}.

Panchayat/Municipality	N (kg ha^{-1})		P (kg ha^{-1})		K (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	217 ± 40.9	138-251	22.9 ± 10.5	10.6-36.1	535 ± 176	213-750
Kainakary	355 ± 68.9	226-451	22.3 ± 8.80	10.4-35.9	662 ± 202	370-986
Champakulam	367 ± 124	163-564	16.9 ± 9.15	7.18-28.9	530 ± 161	258-750
Nedumudi	338 ± 54.7	276-376	8.49 ± 2.02	6.25-10.2	448 ± 80.8	358-515
Pulinkunnu	403 ± 71.1	288-489	16.5 ± 9.06	7.64-30.6	372 ± 247	123-829
Veliyanad	602 ± 45.2	564-652	7.56 ± 1.19	6.25-8.57	258 ± 78.4	202-347
Neelamperoor	545 ± 16.2	527-564	7.29 ± 0.81	6.48-8.10	283 ± 121	157-392
Kavalam	520 ± 86.0	414-602	9.15 ± 1.56	7.41-11.1	540 ± 363	123-974
Muttar	420 ± 79.8	364-477	5.79 ± 1.31	4.86-6.71	302 ± 47.5	269-336
Ramankary	399 ± 35.8	364-464	7.68 ± 2.33	5.09-10.6	381 ± 120	157-482
Ambalappuzha South	364 ± 104	251-489	24.2 ± 9.20	13.9-32.4	504 ± 369	134-885
Purakkad	368 ± 80.6	276-427	9.57 ± 0.35	9.26-9.96	672 ± 237	493-941
Thakazhi	389 ± 135	276-539	9.49 ± 2.55	6.95-12.0	657 ± 191	437-784
Edathua	439 ± 36.9	401-477	7.41 ± 2.86	4.63-10.9	445 ± 159	302-650
Thalavadi	405 ± 88.1	313-489	13.9 ± 3.81	11.1-18.3	437 ± 180	235-582
Pandanad	310 ± 79.6	201-389	8.23 ± 0.98	6.95-9.03	333 ± 98.2	190-414
Puliyur	188 ± 17.7	175-201	12.8 ± 4.42	9.73-15.9	252 ± 39.6	224-280
AEU 4	386 ± 114	138-652	13.9 ± 8.7	4.63-36.1	468 ± 222	123-986

4.2.2.7. Available calcium

The mean values of available calcium content in the soil ranged from 460 mg kg^{-1} to 922 mg kg^{-1} (Table 13). The highest mean value was recorded in Kainakary (922 mg kg^{-1}) followed by Alappuzha Municipality (913 mg kg^{-1}) and the lowest mean value was recorded in Pandanad (460 mg kg^{-1}).

4.2.2.8. Available magnesium

The available magnesium content in the soil samples ranged from 226 to 634 mg kg^{-1} (Table 13). The highest available magnesium content was recorded in the soil from Kainakary (634 mg kg^{-1}) followed by Neelamperoor (522 mg kg^{-1}) and lowest magnesium content was observed in Pandanad (226 mg kg^{-1}).

4.2.2.9 Available sulphur

The available sulphur content in soil samples ranged from 81.2 to 1144 mg kg^{-1} (Table 13). The highest mean value for available sulphur was recorded in Neelamperoor (1144 mg kg^{-1}) followed by Kavalam (955 mg kg^{-1}) and the lowest value was recorded in Puliyur (81.2 mg kg^{-1}).

Table 13. Available Ca, Mg and S status in the post flood soils of AEU 4 in Alappuzha district, mg kg^{-1}.

Panchayat/Municipality	Ca (mg kg^{-1})		Mg (mg kg^{-1})		S (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	913 ± 408	540-1440	486 ± 124	360-636	709 ± 114	600-880
Kainakary	922 ± 333	380-1520	634 ± 223	264-948	627 ± 350	176-1204
Champakulam	691 ± 181	480-980	471 ± 81.1	360-600	611 ± 293	233-955
Nedumudi	760 ± 158	640-940	460 ± 34.6	420-480	695 ± 164	542-868
Pulinkunnu	632 ± 102	460-820	369 ± 82.3	300-552	695 ± 248	472-1108
Veliyanad	787 ± 447	480-1300	248 ± 30.2	216-276	564 ± 253	373-852
Neelamperoor	805 ± 236	560-1120	522 ± 217	360-828	1144 ± 124	968-1244
Kavalam	730 ± 135	580-880	489 ± 180	276-672	955 ± 75.1	843-995
Muttar	740 ± 28.3	720-760	396 ± 186	264-528	236 ± 49.5	201-271
Ramankary	817 ± 193	600-1080	408 ± 193	240-696	717 ± 385	294-1125
Ambalappuzha South	530 ± 125	380-680	351 ± 162	120-480	762 ± 329	437-1083
Purakkad	720 ± 329	340-920	380 ± 204	144-504	865 ± 135	780-1022
Thakazhi	680 ± 131	540-800	432 ± 162	300-613	844 ± 449	356-1242
Edathua	630 ± 47.6	580-680	400 ± 54.4	372-482	601 ± 374	273-948
Thalavadi	733 ± 115	600-800	369 ± 113	253-480	223 ± 59.2	157-272
Pandanad	460 ± 36.5	420-500	226 ± 31.1	189-252	188 ± 63.7	125-272
Puliyur	480 ± 226	320-640	234 ± 77.2	180-289	81.2 ± 61.9	37.5-125
AEU 4	729 ± 248	320-1520	429 ± 171	120-948	661 ± 338	37.5-1244

4.2.2.10 Available boron

From the table (Table 14), it is observed that the mean values of available boron ranged from 0.06 to 0.38 mg kg^{-1}. The highest mean value for available boron was recorded in Purakkad (0.38 mg kg^{-1}) followed by Kavalam (0.34 mg kg^{-1}) and the lowest mean value was recorded in Pandanad (0.06 mg kg^{-1}).

Table 14. Available B in the post flood soils of AEU 4 in Alappuzha district, mg kg^{-1}.

Panchayat/Municipality	Available boron (mg kg^{-1})	
	Mean ± SD	Range
Alappuzha Municipality	0.24 ± 0.12	0.14-0.46
Kainakary	0.23 ± 0.11	0.12-0.44
Champakulam	0.30 ± 0.22	0.01-0.58
Nedumudi	0.18 ± 0.12	0.06-0.28
Pulinkunnu	0.08 ± 0.10	0.01-0.30
Veliyanad	0.08 ± 0.09	0.01-0.18
Neelamperoor	0.19 ± 0.23	0.01-0.50
Kavalam	0.34 ± 0.17	0.19-0.57
Muttar	0.08 ± 0.03	0.06-0.10
Ramankary	0.21 ± 0.06	0.12-0.30
Ambalappuzha South	0.18 ± 0.16	0.02-0.33
Purakkad	0.38 ± 0.14	0.25-0.52
Thakazhi	0.23 ± 0.10	0.13-0.32
Edathua	0.14 ± 0.04	0.09-0.18
Thalavadi	0.31 ± 0.03	0.29-0.34
Pandanad	0.06 ± 0.04	0.02-0.10
Puliyur	0.18 ± 0.04	0.15-0.21
AEU 4	0.20 ± 0.14	0.01-0.58

4.2.3 Biological properties

4.2.3.1 Acid phosphatase

Acid phosphatase activity in the study area shows wide variation as inferred from Table 15. The mean values varied from 13.9 to 59.2 µg of p-nitrophenol released g^{-1} soil h^{-1}. The lowest value was reported in Ambalappuzha South (13.9 µg of p-nitrophenol released g^{-1} soil h^{-1}) while the highest value was recorded from Veliyanad panchayat (59.2 µg of p-nitrophenol released g^{-1} soil h^{-1}) followed by Muttar (53.4 µg of p-nitrophenol released g^{-1} soil h^{-1})

Table 15. Acid phosphatase activity in the post flood soils of AEU 4 in Alappuzha district.

Panchayat/Municipality	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})	
	Mean ± SD	Range
Alappuzha Municipality	24.0 ± 8.02	11.0-33.3
Kainakary	30.8 ± 10.6	17.9-51.8
Champakulam	41.9 ± 24.2	21.3-81.7
Nedumudi	38.3 ± 10.0	29.8-49.4
Pulinkunnu	37.5 ± 27.0	13.2-96.1
Veliyanad	59.2 ± 24.8	38.2-86.5
Neelamperoor	26.4 ± 9.55	18.4-40.0
Kavalam	25.7 ± 8.34	20.9-38.2
Muttar	53.4 ± 8.42	47.4-59.4
Ramankary	38.8 ± 16.5	19.1-61.9
Ambalappuzha South	13.9 ± 1.97	11.4-16.2
Purakkad	15.3 ± 0.64	14.5-15.7
Thakazhi	21.8 ± 1.61	20.4-23.5
Edathua	48.4 ± 8.37	38.4-55.6
Thalavadi	35.8 ± 16.9	17.1-49.8
Pandanad	44.0 ± 15.3	21.9-54.3
Puliyur	23.1 ± 7.33	17.9-28.3
AEU 4	33.9 ± 17.9	11.0-96.1

4.3 FORMULATION OF MINIMUM DATA SET (MDS)

Principal Component Analysis (PCA) was used for setting up of minimum data set. All the analyzed soil parameters except soil moisture content were considered as vectors for PCA. The results of PCA revealed seven principal components (PCs) having eigenvalue more than 1, which were selected for the Minimum Data Set. The PCs explained 27 per cent, 12.6 per cent, 10 per cent, 8.8 per cent, 8 per cent, 6.6 per cent and 5.1 per cent of variance respectively. The PCs and the related eigenvalues are illustrated in Table 16.

The factor loading of a variable under a particular PC depicts the contribution of that variable to the PC. The highly weighted variables (within 10 per cent of the highest factor loading) from each PC were retained for selection of attributes for MDS. When more than one variable was retained in a PC, then linear correlation between the variables was worked out. If the correlation between the variables are significant ($r > 0.6$), then each factor was considered important and will be retained in the MDS. When the all variables are well correlated, then only the variables with highest loading factor will be retained for the MDS.

Table16. Eigenvalues of selected PCs

	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigenvalues	5.394	2.517	2.006	1.756	1.596	1.323	1.013
% variance	27	12.6	10	8.8	8	6.6	5.1
Cumulative variance	27	39.6	49.6	58.4	66.3	73	78

Table 17. Loadings (Eigenvectors) of selected PCs

Soil attribute	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Sand	0.371	0.146	0.075	-0.114	-0.101	-0.125	0.016
Silt	-0.325	-0.177	-0.001	0.022	0.249	0.141	-0.056
Clay	-0.287	-0.034	-0.163	0.214	-0.183	0.045	0.055
WSA	0.044	0.407	-0.248	0.238	-0.340	0.030	0.189
MWD	-0.183	0.368	-0.330	0.227	-0.201	-0.041	0.060
Bulk density	0.304	-0.039	-0.352	-0.186	0.111	0.173	0.148
Particle density	0.222	-0.090	0.276	0.226	-0.181	0.267	0.388
Porosity	-0.202	-0.015	0.490	0.299	-0.222	-0.058	0.072
WHC	-0.242	0.090	0.415	0.030	-0.034	-0.221	0.000
pH	0.197	-0.061	-0.051	0.506	0.214	-0.184	0.019
EC	-0.022	0.010	0.143	0.036	0.150	0.713	0.254
OC	-0.354	0.117	-0.245	0.049	-0.066	0.174	-0.029
N	-0.335	-0.013	-0.101	-0.136	0.044	-0.061	-0.076
P	0.239	0.233	0.119	-0.054	-0.024	-0.131	-0.216
K	0.095	0.278	0.072	0.147	0.176	0.342	-0.448
Ca	-0.049	0.373	0.090	-0.065	0.373	-0.140	0.467
Mg	-0.063	0.409	0.073	-0.058	0.387	-0.134	0.186
S	-0.191	0.189	0.150	-0.533	-0.149	0.102	0.064
B	0.028	0.335	0.159	0.119	0.099	0.194	-0.447
Acid phosphatase	-0.106	-0.157	-0.104	0.219	0.465	-0.098	0.028

In the present PCA analysis as observed from Table 14 where the eigenvectors for different principal components are presented. The parameters sand per cent, organic carbon content, available nitrogen in PC 1, per cent of water stable aggregates, available calcium and magnesium in PC 2, porosity in PC 3, pH in PC 4, acid phosphatase in PC 5, EC in PC 6, available calcium, potassium and boron in PC 7 exhibited the highest values for eigenvectors and then linear correlation between the retained variables within a PC was carried out to selected the most promising parameters from each PC. Hence the factors sand per cent, organic carbon content, per cent of water stable aggregates, available magnesium, porosity, pH, acid phosphatase, EC, available calcium, potassium and boron were selected for MDS as represented in Table 18.

Table 18. Selected soil parameters for MDS

PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Sand content	WSA	Porosity	pH	Acid phosphatase	EC	Available B
Organic carbon content	Available Mg					Available Ca
						Available K

4.4 FORMULATION OF SQI

4.4.1 Scoring of parameters

The soil quality evaluation was done as per the procedure described by Larson and Pierce in 1994. The computation details of Soil Quality Index (SQI) are furnished in Table 19. Appropriate scores will be assigned to the indicators selected for MDS. The status of each attribute was categorized into four classes *viz*., Class-I (very good status), Class-II (good status), Class-III (poor status) and Class-IV (very poor) and marks of 4, 3, 2 and 1 were assigned to the classes respectively (Table 19). The weight for each indicator was assigned on the basis of existing soil conditions, cropping pattern and agro-climatic conditions (Kundu *et al.*, 2012; Mukherjee and Lal, 2014; Singh *et al.*, 2017).

Table 19. Soil quality indicators with their weights and classes for the evaluation of soil quality.

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
WSA	10	>90	70 – 90	50 – 70	< 50
Porosity	10	>50	40-50	30-40	<30
Texture (sand %)	10	Loam	Clay loam / Sandy loam	Sand / Clay	Grit
pH	10	6.5-7.5	6-6.5	5.5-6	<5.5
EC	10	<2	2-4	4-8	>8
OC	10	>1	1 – 0.75	0.75 – 0.50	< 0.50
Available K	10	>280	200 – 280	120 – 200	<120
Available Ca	5	>300	250-300	150-250	<150
Available Mg	5	>120	120 – 90	90 – 60	<60
Available B	10	>0.50	0.25 – 0.50	0.10 – 0.25	<0.10
Acid phosphatase	10	>60	30-60	15-30	<30

4.4.2 Soil Quality Index (SQI) and Relative Soil quality Index (RSQI)

By using the formula (SQI = $\sum W_i \times M_i$) the soil quality index (SQI) and Relative Soil Quality Index (RQSI) was worked out and the outcome of the computation are presented in Table 20.

From the perusal of the data on Soil Quality Index (Table 20), it was observed that the values for indices ranged from 262 to 306. The highest mean value for SQI was observed from Veliyanad (306), followed by Thalavadi (303) and the lowest value was recorded from Puliyur panchayat (262) .The values for relative soil quality index for the study area ranged between 65.2 and 76.7 per cent. On rating the locations based on soil quality index, Ambalappuzha South, Pandanad and Puliyur were found to be medium in soil quality while all other panchayats belonged to high soil quality status.

Table 20. SQI and RSQI of post flood soils of AEU 4 in Alappuzha district

Panchayat/Municipality	SQI		RSQI (%)	
	Mean ± SD	Range	Mean ± SD	Range
Alappuzha Municipality	285 ± 12.2	270-300	71.2 ± 3.06	67.5-75.0
Kainakary	293 ± 14.1	270-310	73.3 ± 3.53	65.6-76.7
Champakulam	300 ± 11.5	280-310	75.0 ± 2.88	65.0-75.8
Nedumudi	286 ± 11.5	280-300	71.7 ± 2.68	70.6-75.8
Pulinkunnu	282 ± 17.5	260-310	70.6 ± 3.37	65.6-76.7
Veliyanad	306 ± 15.3	290-320	76.7 ± 3.82	72.5-80.0
Neelamperoor	297 ± 5.00	290-300	74.4 ± 1.25	72.5-75.0
Kavalam	282 ± 12.6	270-300	70.6 ± 3.14	67.5-75.0
Muttar	295 ± 7.07	290-300	73.7 ± 1.76	72.5-75.0
Ramankary	288 ± 17.2	260-310	72.1 ± 4.30	65.0-77.5
Ambalappuzha South	265 ± 26.2	240-290	65.6 ± 6.57	60.0-72.5
Purakkad	287 ± 5.77	280-290	71.7 ± 1.44	70.0-72.5
Thakazhi	296 ± 20.8	280-320	74.1 ± 5.20	70.0-80.0
Edathua	300 ± 11.5	290-310	75.0 ± 2.88	72.5-77.5
Thalavadi	303 ± 15.3	290-320	75.5 ± 3.83	72.5-80.0
Pandanad	267 ± 12.6	260-280	66.8 ± 3.14	62.5-70.0
Puliyur	262 ± 7.07	260-270	65.2 ± 1.76	65.0-67.5
AEU 4	288 ± 17.6	240-320	72.1 ± 4.41	62.5-80.0

4.5 SOIL NUTRIENT INDEX

Soil nutrient index of organic carbon, available nitrogen, phosphorus and potassium of the 17 panchayats were computed using the formula $N.I = [1x\ N_L + 2\ x\ N_M + 3\ x\ N_{H]}]/N_T$ and the results are presented in Table 21.

From the Table 21, it is inferred that Nutrient index for organic carbon of all the panchayats were greater than 2.33 which implies the high fertility status of the area. The highest nutrient index value for organic carbon was reported as 3.00 in Kainakary, Nedumudi, Pulinkunnu, Veliyanad, Neelamperoor, Kavalam, Muttar, Ramankary, Purakkad, Thakazhi, Edathua, Pandanad and Puliyur panchayats. Thalavadi recorded the lowest nutrient Index value for organic carbon (2.67).

In the case of Nutrient index values for nitrogen (Table 21), it is observed that the values ranged between 1.00 and 3.00. Among the 17 panchayats, the lowest nutrient index was recorded from Alappuzha Municipality and Puliyur panchayat whereas the highest value was recorded from Veliyanad (3.00) followed by Kavalam (2.50). Veliyanad panchayat fall under high status for available nitrogen whereas most of the panchayats fall under medium fertility status.

From Table 21 it is observed that phosphorus status in soil showed wide variation. The highest nutrient index value obtained for available phosphorus was 3.00 and it was recorded from Kainakary. The lowest value recorded was 1.00 and it was reported from 7 panchayats *viz.*, Veliyanad, Neelamperoor, Muttar, Ramankary, Purakkad, Edathua and Pandanad. Alappuzha Municipality, Champakulam, Nedumudi and Thalavadi showed medium fertility status for available phosphorus.

In the case of potassium, nutrient index showed high fertility status in all the panchayats with a nutrient index value greater than 2.33.The values ranged from 2.33 to 3.00. The highest value recorded was 3.00 and it was reported from Nedumudi, Purakkad, Thakazhi and Edathua while the lowest value was noted from Kainakary and Veliyanad (2.33).

Table 21. Nutrient Index of organic carbon, available N, P, and K of post flood soils of AEU 4 in Alappuzha district

Panchayat/ Municipality	Organic Carbon		N		P		K	
	N.I	Nutrient Status	N.I	Nutrient Status	N.I	Nutrient Status	N.I	Nutrient Status
Alappuzha Municipality	2.83	High	1	Low	2.17	Medium	2.83	High
Kainakary	3.00	High	1.80	Medium	3.00	High	2.33	High
Champakulam	2.86	High	1.71	Medium	2.12	Medium	2.86	High
Nedumudi	3.00	High	1.67	Medium	1.67	Medium	3.00	High
Pulinkunnu	3.00	High	2.00	Medium	2.00	Medium	2.38	High
Veliyanad	3.00	High	3.00	High	1.00	Low	2.33	High
Neelamperoor	3.00	High	2.25	Medium	1.00	Low	2.50	High
Kavalam	3.00	High	2.50	High	1.25	Low	2.50	High
Muttar	3.00	High	2.00	Medium	1.00	Low	2.50	High
Ramankary	3.00	High	2.00	Medium	1.00	Low	2.83	High
Ambalappuzha South	2.75	High	1.75	Medium	2.50	High	2.50	High
Purakkad	3.00	High	2.00	Medium	1.00	Low	3.00	High
Thakazhi	3.00	High	1.67	Medium	1.33	Low	3.00	High
Edathua	3.00	High	2.00	Medium	1.00	Low	3.00	High
Thalavadi	2.67	High	2.00	Medium	2.00	Medium	2.67	High
Pandanad	3.00	High	1.75	Medium	1.00	Low	2.75	High
Puliyur	3.00	High	1.00	Low	1.50	Low	2.50	High

4.6 LAND QUALITY INDEX (LQI)

The land quality index was computed by using the formula, soil organic carbon (SOC) stock (kg m^{-2}) = soil organic carbon (%) x Bulk density (Mg m^{-3}) x Soil depth (m) x 10 and the computed values are illustrated in Table 22.

From the Table 22, it is observed that SOC stock value of the study area varied from 3.54 to 8.39 kg m^{-2}. The highest value of SOC stock was recorded from Purakkad (8.39 kg m^{-2}) followed by Veliyanad (6.47 kg m^{-2}) and the lowest value was recorded from Puliyur (3.54 kg m^{-2}). LQI of all the panchayats belonged to low category except Veliyanad and Purakkad.

Table 22. SOC stock and LQI of post flood soils of AEU 4 in Alappuzha district

Panchayat/Municipality	SOC stock (Mg ha^{-1})	SOC stock (kg m^{-2})		LQI
		Mean ± SD	Range	
Alappuzha Municipality	14.2-63.9	3.90 ± 1.68	1.42-6.39	Low
Kainakary	25.6-49.5	3.74 ± 0.77	2.56-4.95	Low
Champakulam	19.2-64.3	3.87 ± 1.50	1.92-6.43	Low
Nedumudi	31.2-41.5	3.66 ± 0.52	3.12-4.15	Low
Pulinkunnu	32.3-61.0	4.41 ± 0.90	3.23-6.10	Low
Veliyanad	48.1-89.0	6.47 ± 2.15	4.81-8.90	Medium
Neelamperoor	40.5-65.4	5.38 ± 1.24	4.05-6.54	Low
Kavalam	40.8-67.9	5.65 ± 1.23	4.08-6.79	Low
Muttar	35.9-47.7	4.18 ± 0.84	3.59-4.77	Low
Ramankary	17.7-75.2	4.18 ± 2.43	1.77-7.52	Low
Ambalappuzha South	24.1-47.8	4.01 ± 1.09	2.41-4.78	Low
Purakkad	82.6-85.9	8.39 ±0.17	8.26-8.59	Medium
Thakazhi	40.4-60.3	5.15 ±1.01	4.04-6.03	Low
Edathua	32.5-59.3	5.15 ± 1.26	3.25-5.93	Low
Thalavadi	19.0-51.0	4.25 ± 1.65	1.90-5.10	Low
Pandanad	40.5-79.0	5.60 ± 1.86	4.05-7.90	Low
Puliyur	31.3-39.6	3.54 ± 0.78	3.13-3.96	Low
AEU 4	14.2-89.9	4.58 ± 1.67	1.42-8.59	

4.7 GENERATION OF MAPS USING GIS

GIS based thematic maps were generated for sampling location, soil texture, soil pH, organic carbon, available macronutrients, calcium, magnesium, sulphur, boron, soil quality index, nutrient index and land quality index.

4.8 CORRELATION STUDIES

Correlation of physical, chemical and biological attributes of study area were determined and correlated values are presented in Tables 23 to 25.

From the correlation matrix (Table 23) it was clear that bulk density was positively correlated with particle density, sand content and negatively correlated with porosity, silt content, clay content, moisture content and water holding capacity. Among these, correlation with porosity (0.862**) was highly significant. Particle density of soil was positively correlated with sand content and mean weight diameter, negatively correlated with silt content and clay content. Among these correlation with sand content is highly significant (0.350**). Water holding capacity and moisture content recorded positive correlation with porosity and among them correlation with water holding capacity was highly significant (0.623**). Sand content showed significant negative correlation with silt content, clay content, moisture content and water holding capacity and positive correlation with bulk density (0.480**), particle density (0.350**), water stable aggregate (0.236*) and mean weight diameter (0.268*). Silt content had positive correlation with clay content, moisture content and water holding capacity. Clay per cent had significant positive correlation with mean weight diameter (0.414**). Moisture content had a significantly positive correlation with water holding capacity (0.744**).

Table 23. Correlation studies of the physical properties in the post flood soils of AEU 4 in Alappuzha district

	Bulk density	Particle density	Porosity	Sand	Silt	Clay	WSA	MWD	Moisture Content	WHC
Bulk density	1.000									
Particle density	**0.289****	1.000								
Porosity	**-0.862****	0.219NS	1.000							
Sand	**0.480****	**0.350****	**-0.320****	1.000						
Silt	**-0.383****	**-0.297****	**0.251***	**-0.906****	1.000					
Clay	**-0.432****	**-0.286***	**0.295***	**-0.724****	**0.363****	1.000				
WSA	0.085NS	0.081NS	-0.036NS	**0.236***	**-0.360****	0.068NS	1.000			
MWD	-0.196NS	**0.293***	0.061NS	**0.268***	0.107NS	**0.414****	**0.697****	1.000		
Moisture Content	**-0.634****	-0.203NS	**0.547****	**-0.284***	**0.278***	0.171NS	-0.129NS	0.150NS	1.000	
WHC	**-0.667****	-0.113NS	**0.623****	**-0.337****	**0.345****	0.180NS	-0.132NS	0.132NS	**0.744****	1.000

*- Significant at 5% level

**- Significant at 1% level

The correlation matrix of organic carbon with physical attributes of soil (Table 24) clearly depicts that organic carbon content exhibited significant positive correlation with silt content (0.583**), clay content (0.606**), mean weight diameter (0.651**), moisture content (0.248*) and water holding capacity (0.268*). Among these, correlation with clay content is highly significant (0.606**). Bulk density (-0.390**), particle density (-0.466**) and sand content (-0.707**). Among the various parameters, correlation with sand per cent is highly significant (-0.707**).

The correlation matrix for soil chemical characteristics with biological attribute (Table 25) clearly depicts that soil pH had significant negative correlation with EC (-0.595**), organic carbon content (-0.384**), available nitrogen (-0.356**) and available sulphur (-0.735**). Among these, correlation with available sulphur (-0.753**) is highly significant. With respect to EC, significant positive correlation with available nitrogen (0.244*), calcium (0.282*), magnesium (0.350**) and sulphur (0.635**) was noticed. Among the parameters, correlation with available sulphur (0.635**) was highly significant. Organic carbon content in the soil exhibited positive correlation with available nitrogen (0.626**) and sulphur (0.314**) whereas a negative correlation with available phosphorus (-0. 492**).

In the case of major nutrients, available nitrogen correlated negatively with available phosphorus (-0.367**) and positively with available sulphur (0.418**) and acid phosphatase (0.243*). Available phosphorus recorded significant positive correlation with available potassium (0.250*) and negative correlation with acid phosphatase activity (-0.275*) while available potassium recorded positive correlation with available boron content in the soil (0.358**).

In the case of secondary nutrients, available calcium content in the soil showed positive correlation with available magnesium (0.640**) and available sulphur (0.231*) whereas available magnesium recorded positive correlation with available boron content (0.266*).

Table 24. Correlation between organic carbon content and physical properties

	Organic carbon	Bulk density	Particle density	Porosity	Sand	Silt	Clay	WSA	MWD	Moisture Content	WHC
Organic carbon	1.000										
Bulk density	**-0.390****	1.000									
Particle density	**-0.466****	**0.289***	1.000								
Porosity	0.173NS	**-0.862****	0.219NS	1.000							
Sand	**-0.707****	**0.480****	**0.350****	**-0.320****	1.000						
Silt	**0.583****	**-0.383****	**-0.297****	**0.251***	**-0.906****	1.000					
Clay	**0.606****	**-0.432****	**-0.286***	**0.295***	**-0.724****	**0.363****	1.000				
WSA	0.180NS	0.085NS	0.081NS	-0.036NS	**0.236***	**-0.360****	0.068NS	1.000			
MWD	**0.651****	-0.196NS	**-0.293***	0.061NS	**-0.268***	0.107NS	**0.414****	**0.697****	1.000		
Moisture Content	**0.248***	**-0.634****	-0.203NS	**0.547****	**-0.284***	**0.278***	0.171NS	-0.129NS	0.150NS	1.000	
WHC	**0.268***	**-0.667****	-0.113NS	**0.623****	**-0.337****	**0.345****	0.180NS	-0.132NS	0.132NS	**0.744****	1.000

*- Significant at 5% level

**- Significant at 1% level

Table 25. Correlation between soil chemical and biological properties

	pH	EC	Organic carbon	N	P	K	Ca	Mg	S	B	Acid phosphatase
pH	1.000										
EC	**-0.595****	1.000									
Organic carbon	**-0.384****	0.216^{NS}	1.000								
N	**-0.356****	**0.244***	**0.626****	1.000							
P	0.157^{NS}	0.025^{NS}	**-0.492****	**-0.367****	1.000						
K	0.147^{NS}	0.045^{NS}	-0.059^{NS}	-0.159^{NS}	**0.250***	1.000					
Ca	0.027^{NS}	**0.282***	0.063^{NS}	0.075^{NS}	0.072^{NS}	0.077^{NS}	1.000				
Mg	-0.049^{NS}	**0.350****	0.133^{NS}	0.037^{NS}	0.147^{NS}	0.197^{NS}	**0.640****	1.000			
S	**-0.735****	**0.635****	**0.314****	**0.418****	-0.120^{NS}	-0.074^{NS}	**0.231***	0.204^{NS}	1.000		
B	0.048^{NS}	0.062^{NS}	0.033^{NS}	-0.174^{NS}	0.209^{NS}	**0.358****	0.182^{NS}	**0.266***	0.051^{NS}	1.000	
Acid Phosphatase	0.125^{NS}	0.001^{NS}	0.132^{NS}	**0.243***	**-0.275***	-0.037^{NS}	0.066^{NS}	0.061^{NS}	**-0.260***	-0.117^{NS}	1.000

*- Significant at 5% level

**- Significant at 1% level

Discussion

5. DISCUSSION

The present study "Assessment of soil quality in the post-flood scenario of AEU 4 in Alappuzha District of Kerala and generation of GIS maps" was envisaged during the year 2018-20 to evaluate the soil quality of post flood soils of AEU 4 in Alappuzha district. The results of the study are discussed in this chapter based on physical, chemical and biological characteristics of the soil, soil quality index, land quality index and nutrient indices

5.1 CHARACTERIZATION OF SOIL SAMPLES

5.1.1 Physical attributes

5.1.1.1 Bulk density

The bulk density values recorded from the study area were generally low, most of the samples had a bulk density value less than the optimum bulk density of 1.33 Mg m^{-3}. The mean values for bulk density varied from 0.66 Mg m^{-3} to 1.43 Mg m^{-3}.

About 78.67 per cent of samples had a bulk density value less than 1.2 Mg m^{-3}, 9.33 per cent of samples in the range of 1.2 to 1.4 Mg m^{-3} and 12 per cent of samples were in the range 1.4 to 1.6 Mg m^{-3} (Fig. 3). The lowest mean value for bulk density was recorded from Neelamperoor might be attributed to the highest clay per cent (42.3 per cent) and organic carbon content (5.39 per cent). The lowest value for bulk density was reported from Pandanad where the organic carbon content was 2.60 per cent.

From the study it is revealed that a negative correlation existed between bulk density and organic carbon content with r = -0.390** which indicates the inverse relationship between bulk density and organic carbon content. Similar results were obtained by Federer *et al.* (1993), Prevost (2004), Mestdagh *et al.* (2006) and Sakin (2012) indicating the negative correlation between bulk density and soil organic carbon content is universal. These findings also corroborated with the findings of Nath (2016). Clayey soils tend to have lower bulk densities and higher porosities than sandy soils Chaudari *et al.*

(2013). In the present study, significant negative correlation between bulk density with clay content (-0.432**) and silt content (-0.383**) supports the results obtained.

5.1.1.2 Particle density

From the study conducted in the flood affected panchayats of AEU 4, a similar trend was noticed for particle density of the soil samples as that of that by bulk density and the mean values varied from 1.67 to 2.31 Mg m^{-3} (Table 7). About 81.34 per cent of samples reported to have a particle density lower than 2.2 Mg m^{-3}. 13.33 per cent of soils samples had particle density in the range 2.2 to 2.4 Mg m^{-3} and 5.33 per cent of samples had particle density greater than 2.6 Mg m^{-3} (Fig. 4). The highest and the lowest mean value for particle density was recorded from Alappuzha Municipality and Kavalam respectively.

The role of organic matter in lowering the particle density of the soil is evident from the study and a significant negative correlation was existed between particle density and organic carbon content (-0.466**). Organic matter content present in soil have a great influence on particle density of the soil and surface soils having higher organic matter content will have lower particle density (Brady and Weil, 1999). The lowest value for particle density was reported from Kavalam where the organic carbon content was 4.04 per cent which is in the high range. The decrease in particle density with increasing SOC concentration is attributed to the dilution effect of the mineral particles (Hillel, 1998). Similar findings were reported by Ball *et al.* (2000).

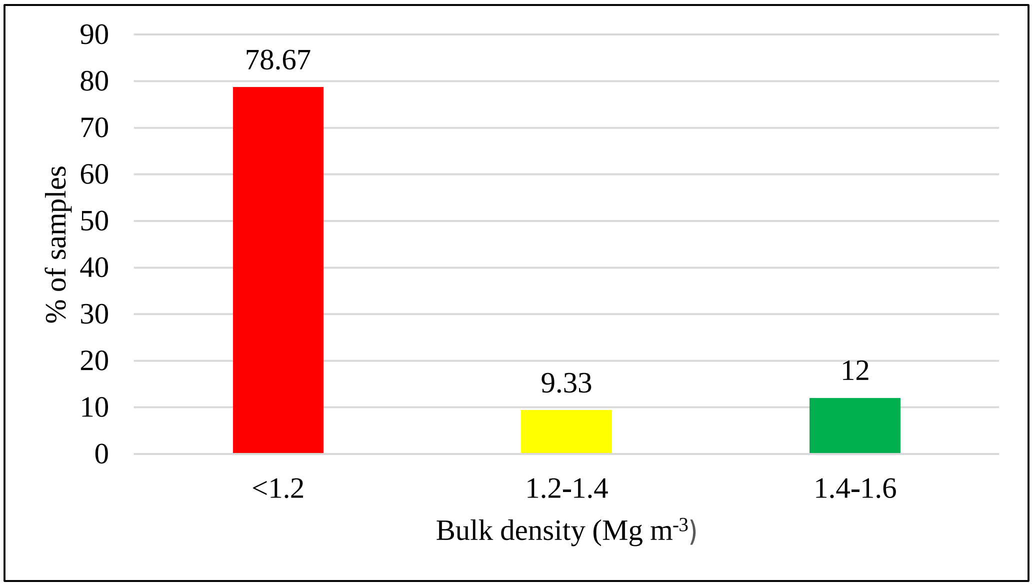

Fig.3 Frequency distribution of bulk density in the post flood soils of AEU 4 in Alappuzha district

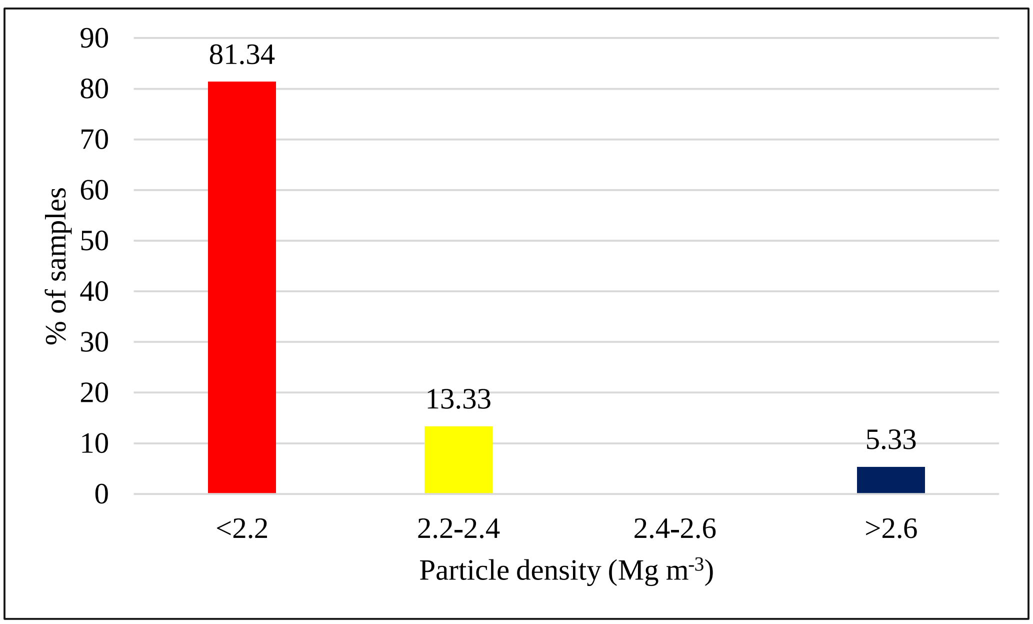

Fig. 4 Frequency distribution of particle density in the post flood soils of AEU 4 in Alappuzha district

5.1.1.3 Porosity

From the data presented in Table 7, it is observed that the mean values for soil porosity in the study area varied from 28.9 to 64.7 per cent and strong negative correlation existed between bulk density and porosity (-0.862**). The highest value for soil porosity was reported from Neelamperoor (64.7 per cent) where the bulk density was the minimum and organic carbon content was maximum. The lowest value for porosity was observed from Pandanad (28.9 per cent) where bulk density reported the maximum mean value.

The trend followed by soil porosity in the study area is depicted in Fig.5 and it was noticed that for 51 per cent of soil samples, soil porosity were in the range of 30 to 50 per cent, 37 per cent of samples had a porosity in between the range 50 to 70 per cent, 4 per cent of samples had porosity greater than 70 per cent and only 8 per cent of samples had a porosity less than 30 per cent.

Soil porosity describes the portion of soil volume occupied by pore spaces and it is influenced by soil texture, bulk density and organic matter content present in the soil. Porosity increases with soil organic matter content and an inverse relationship exists between bulk density and soil porosity. Higher the bulk density, lower will be the porosity. Chaudhari *et al.* (2013) studied the physical characteristics of Coimbatore soils and stated that bulk density of a soil is inversely related to the porosity and found strong negative correlation (-0.886) between porosity and bulk density of soil samples. High porosity in the study area might be attributed by low bulk density and high organic carbon content present in the soil.

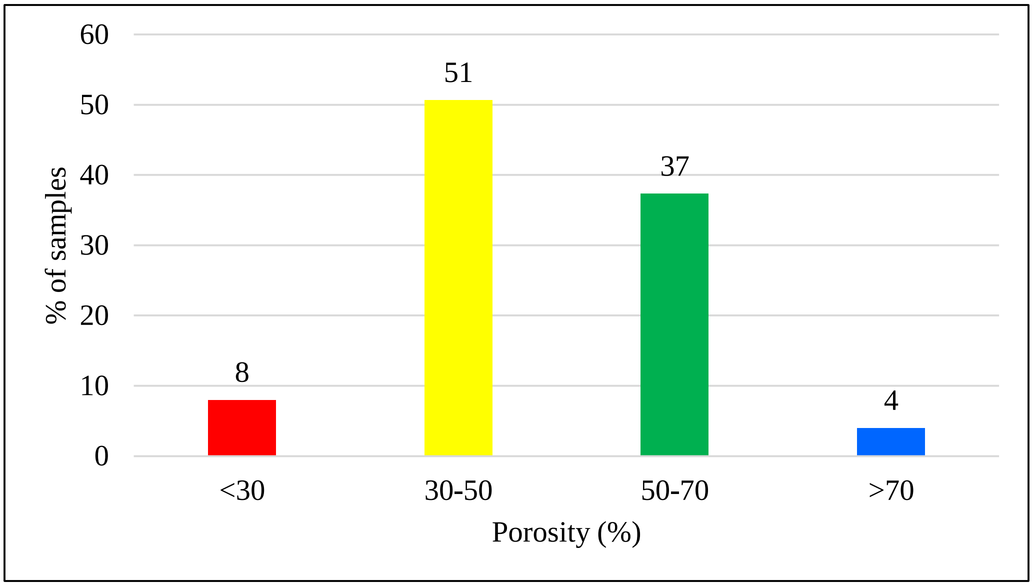

Fig.5 Frequency distribution of porosity (%) of the post flood soils of AEU 4 in Alappuzha district

5.1.1.4 Texture

Soils of Kuttanad are mixtures of clay and sand in different proportions. (GOK, 1971). Sruthi *et al.* (2017) opined that the soil texture of Kuttanad agroecosystem varied from sandy to sandy loam, loamy sand and sandy clay loam. AEU 4 of Alappuzha district is subjected to seasonal flooding every year which led to the deposition of silt and clay in this area (GOK, 2019).

From the present study in the flood affected soils of AEU 4**,** it was observed that there was wide variation in the sand, silt and clay content in the samples collected. Mean value for sand content were in the range of 22.7 to 73.5 per cent. The highest and the lowest mean value for sand content were reported from Ambalappuzha South and Neelamperoor respectively. Silt content in the AEU 4 of Alappuzha district varied from 8.33 to 45 per cent and the highest and the lowest silt content was reported from Veliyanad and Alappuzha Municipality respectively. Clay content in the study area ranged from 20.6 to

42.3. Neelamperoor (42.3 per cent) recorded the highest value for clay content and the lowest value was reported from Alappuzha Municipality (20.6).

The trend followed by soil texture in the study area is depicted in the Fig 6. Sandy clay loam was the predominant soil texture in the study area (41.34 per cent) which was followed by clay loam (21.34 per cent) and sandy loam (17.33 per cent). Similar results were reported by Thampatti and Jose (2000) and Beena (2005).

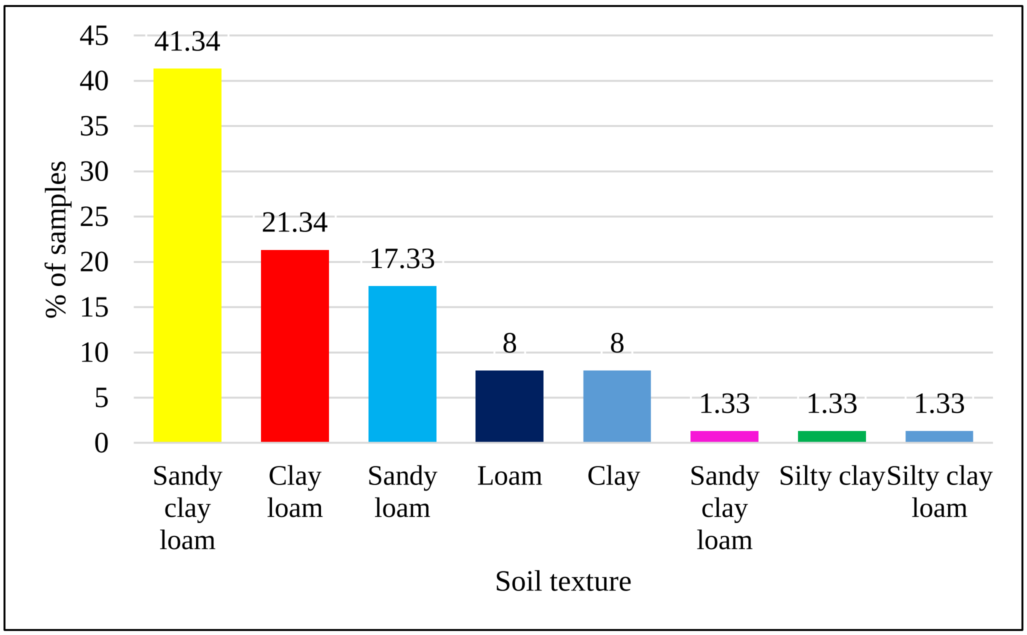

Fig.6 Frequency distribution of soil texture in the post flood soils of AEU 4 in Alappuzha district

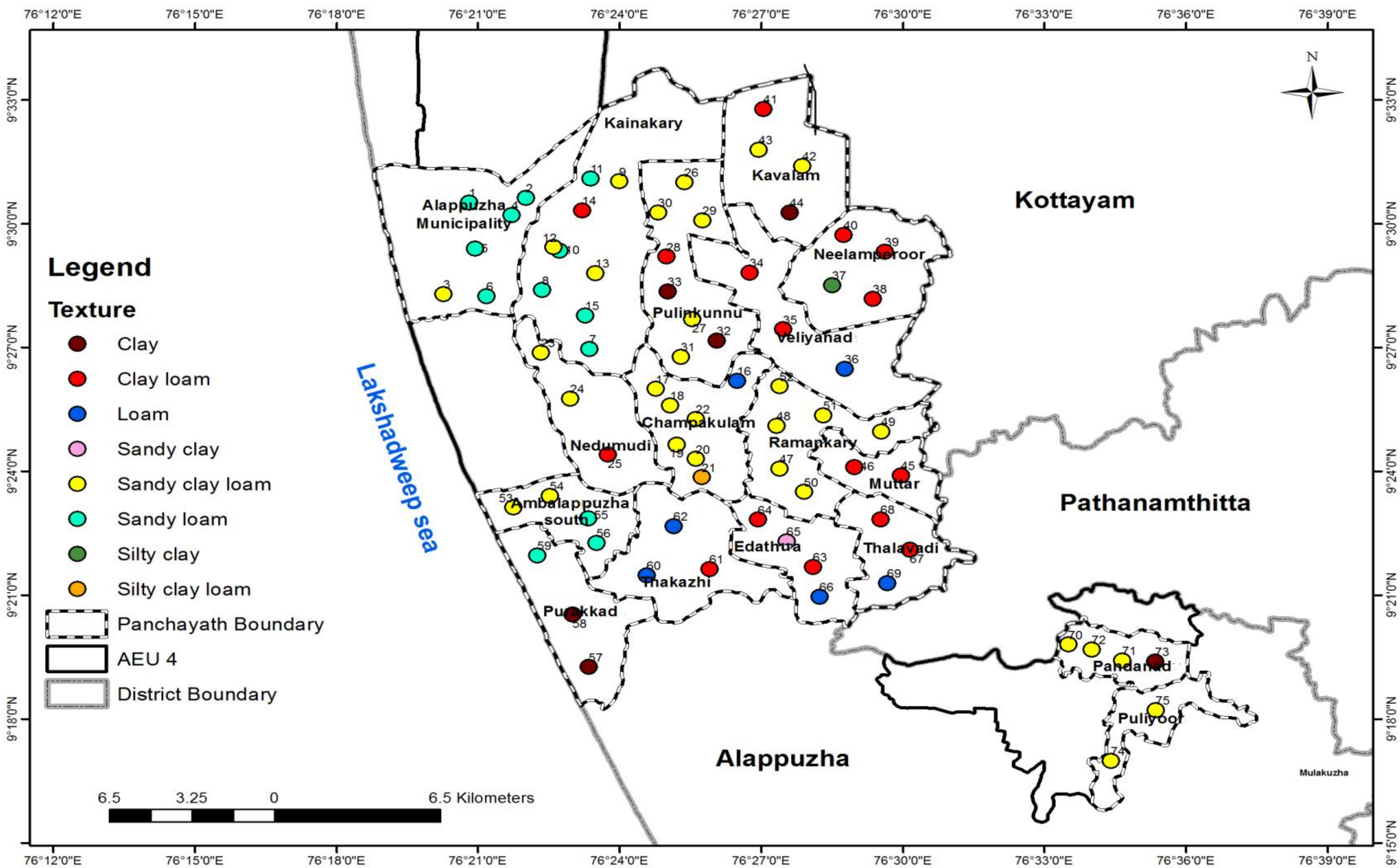

Fig.7 Spatial distribution of soil texture in post flood soils of AEU 4 in Alappuzha district

5.1.1.5 Water holding capacity

Water holding capacity of the soils of AEU 4 in Alappuzha district varied from 32.0 to 58.5 per cent and the highest value for water holding capacity was reported from Thakazhi (58.5 per cent). The frequency distribution of water holding capacity of the study area (Fig. 8) revealed that about 57.33 per cent of samples recorded a water holding capacity in the range 30 to 50 per cent while 38.67 per cent of samples had a water holding capacity in the range 50 to 70 per cent.

From the study it is inferred that water holding capacity of the soils is influenced predominantly by soil texture and organic carbon content. The highest water holding capacity was recorded from Thakazhi might be due to the high amount of organic carbon (3.56 per cent), porosity (53.8 per cent) and loamy texture. Clay and silt particles of the soil have a much larger surface area than the sand particles. This large surface area allows the soil to hold a greater quantity of water and this might have one of the reason for the increased water holding capacity of these soils. Significant positive correlations were reported for water holding capacity with organic carbon status (0.268*) and with porosity (0.623**) in AEU 4. Deb *et al.* (2014) stated that water holding capacity is affected by soil porosity and reported a significant positive correlation between water holding capacity and porosity (0.572*). Similar results were reported by Nath (2016).

5.1.1.6 Soil moisture content

Soil moisture content in the post flood soils of Kuttanad was in the range of 16.4 to 52.2 per cent and the highest value was recorded from Veliyanad. About 72 per cent of soils were having moisture content greater than 25 per cent in the present study. 18.67 per cent of soil had a moisture content in the range 15 to 25 and 9.33 per cent soils with a moisture content in the range 10 to 15 per cent (Fig 9).

Soil moisture content quantify the amount of water the soil contains and is influenced by organic carbon content, clay content, bulk density and porosity (Deb *et al.*, 2014). From the study it is observed that a significant positive correlation existed between organic carbon and moisture content (0.248*). Thus it is inferred that moisture content in the soil is also influenced by the organic matter content present in the soil.

The presence of organic matter to the soil usually increases the moisture content of the soil as the addition of organic matter increases the number of micropores and macropores in the soil either by aggregating soil particles together or by creating favorable living conditions for soil organisms. Soil organic matter can hold up to 20 times their weight in water (Reicosky, 2005). These reasons can be attributed to the highest mean value for soil moisture content in Veliyanad where the organic matter content is high.

5.1.1.7 Aggregate stability

Aggregate stability of the samples were represented by per cent of water stable aggregates (WSA) and mean weight diameter (MWD). The highest value for per cent water stable aggregates and MWD were reported from Purakkad whereas the lowest value for per cent water stable aggregates and MWD were reported from Muttar (Table 10).

From the Fig 10 and 11, it is noted that nearly 48 per cent of samples were reported to have per cent water stable aggregate in the range 50 to 70 per cent, 49.33 per cent soils with water stable aggregates greater than 70 per cent, 41.33 per cent of samples had MWD in the range 1.5 to 2.0 mm and 14 per cent of soils had MWD greater than 2 mm.

Aggregate stability of the soil depends on the interaction of primary particle with organic constituents and increases with organic matter present in soil (Tisdall and Oades, 1982). A significant correlation between MWD and organic carbon content is noticed in the present study (0.651**). The highest value for WSA and MWD reported from Purakkad might be due to the high organic carbon content**.**

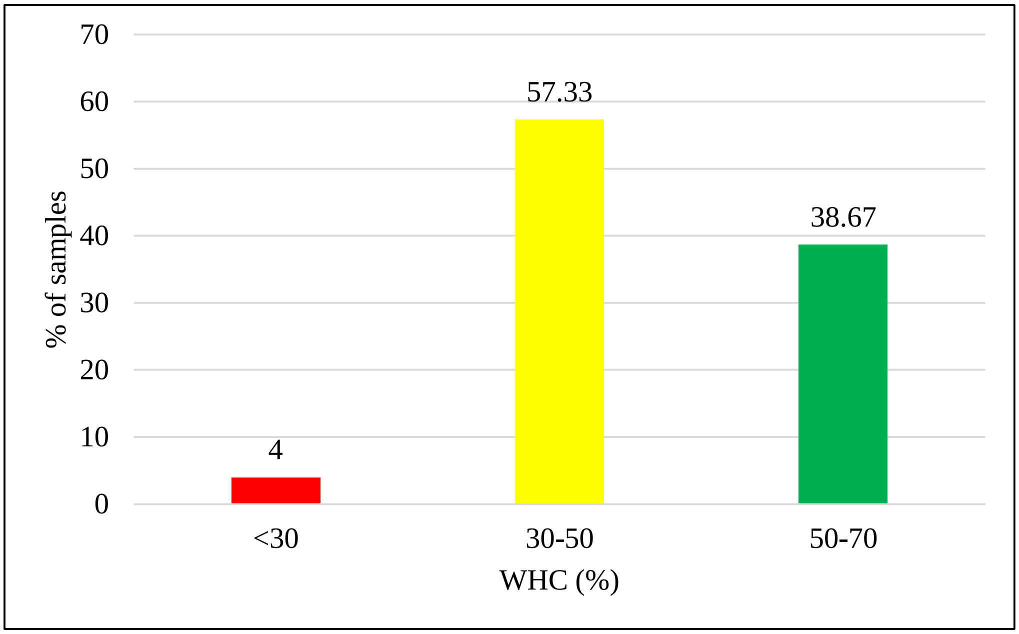

Fig 8. Frequency distribution of water holding capacity in the post flood soils of AEU 4 in Alappuzha district

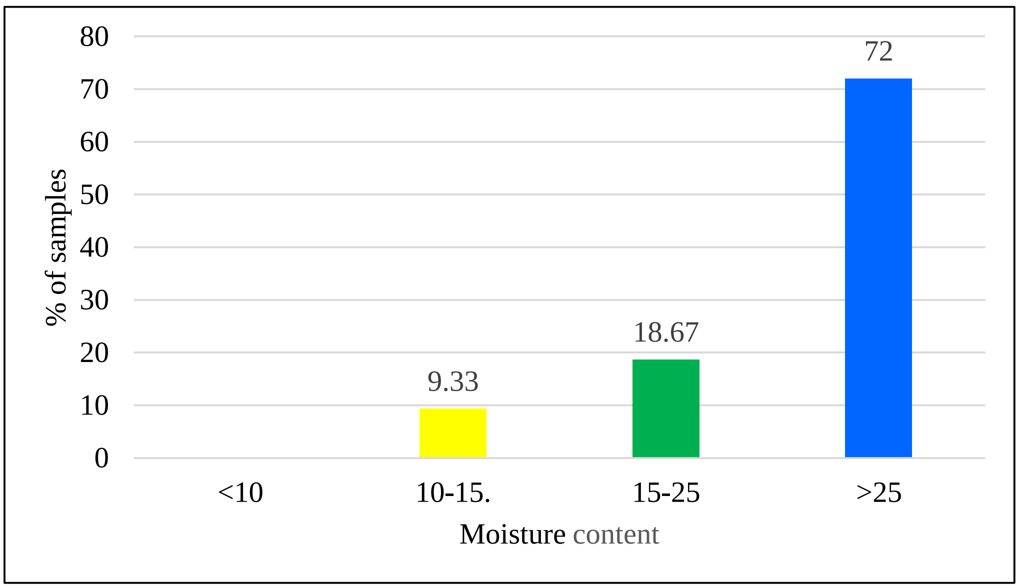

Fig.9 Frequency distribution of moisture content in the post flood soils of AEU 4 in Alappuzha district

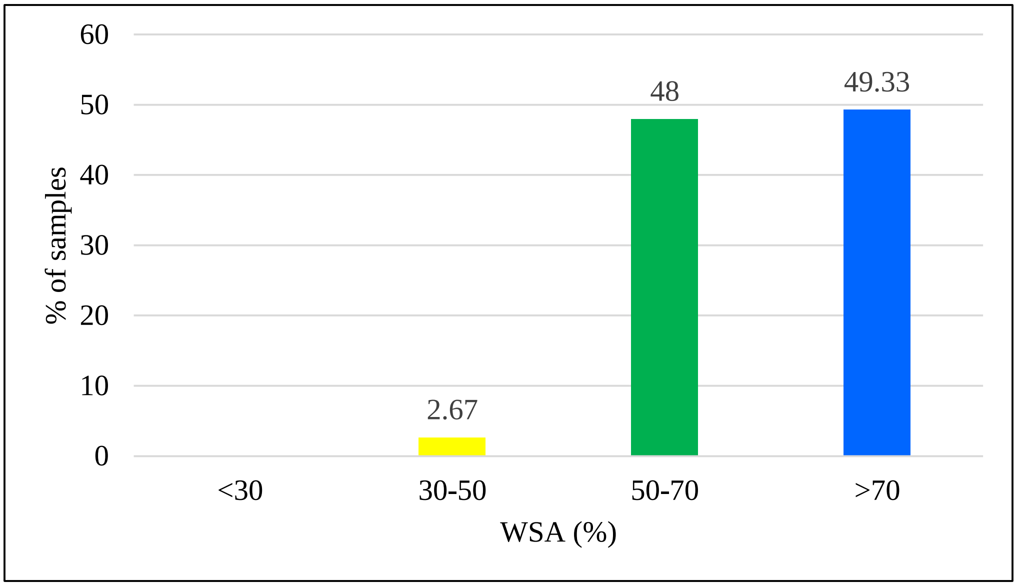

Fig. 10 Frequency distribution of water stable aggregates in the post flood soils of AEU 4 in Alappuzha district

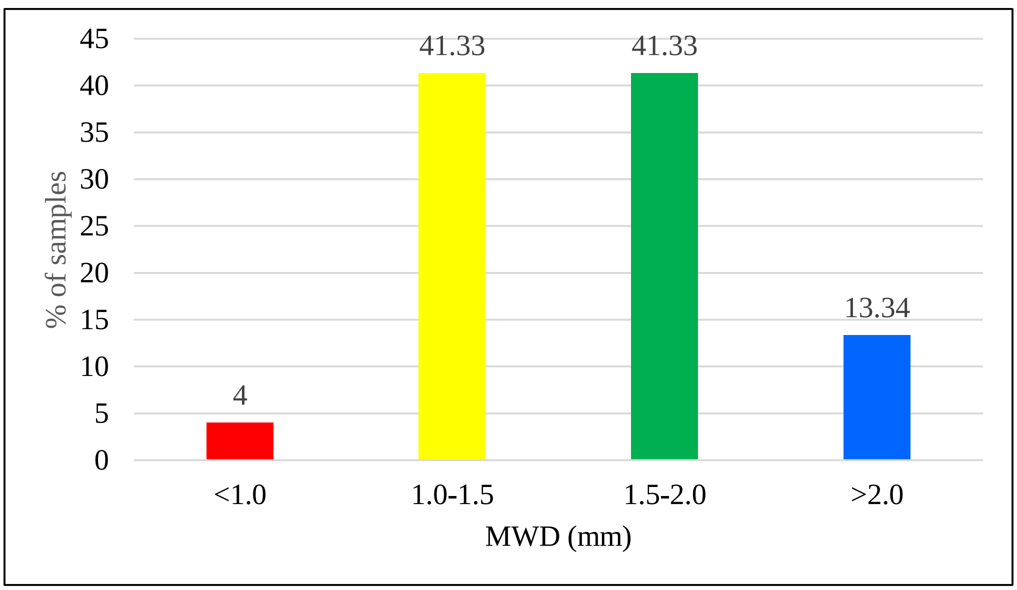

Fig.11 Frequency distribution of MWD in the post flood soils of AEU 4 in Alappuzha district

5.1.2 Chemical attributes

5.1.2.1. Soil pH

Kuttanad soils are considered as problematic soils due to its extreme acidity. Soils of Kuttanad shows seasonal fluctuations for soil pH and a drop in soil pH is reported during summer months due to oxidation of iron pyrite present in the soil to sulphuric acid (Kurup and Aiyer, 1973). Flooding of acid wetland soils cause an increase of soil acidity (Sahrawat, 2012).

In the present study, it is observed that the soils of the study area were extremely acidic in nature due to the presence of large quantities of sulphides which on oxidation produces sulphuric acid. Organic acid production during the decomposition of organic matter have aggravated the extent of acidity (Beena, 2005). The mean values for soil pH ranged from 3.54 to 4.79 (Table 11). The lowest mean value for soil pH recorded in Neelamperoor (3.54) and highest in Puliyur (4.79). From the present study, a significant negative correlation was reported between soil pH and available sulphur content (r = -0.735**). The lowest value for soil pH was observed from Neelamperoor where the available sulphur content reported the highest value (1144 mg kg^{-1}) and highest value for soil pH was recorded from Puliyur where sulphur content reported the lowest value (81.2 mg kg^{-1}). The highest mean value recorded for organic carbon in Neelamperoor (5.39 per cent) might be one of the reason for the extreme acidity in this panchayat. Production of organic acids by anaerobic decomposition of organic matter might have decreased the pH values and aggravated acidity in Kuttanad which varied from 2.6 to 5.9 as opined by Thampatti (1997).

From the Fig. 13, it is observed that about 78.67 per cent of soil samples were extremely acidic, 13.33 per cent of soils very strongly acidic 5.33 per cent of soils ultra-acidic and the remaining soils belonged to strongly acidic category which is in contradiction to the pre-flood data (Appendix IV). In the pre-flood condition only 21 per cent of samples belonged to extremely acidic category whereas 24.76 and 25.47 per cent of soils belonged to very strongly acid and strongly acid category respectively. Thus it can be observed that acidity of soils of the study area has been increased after the flood in 2018.

The prevention of saline water washing slowed the replacement of $A1^{3+}$ from the exchange sites, which resulted in the lowering of soil pH. The frequent cultivation activities and soil drying before harvest had accelerated the development of acidity due to the oxidation of pyrites (Thampatti and Jose, 2000).

5.1.2.2. Electrical conductivity

Electrical conductivity of soil is a measure of salts present in the soils and it is affected by cropping irrigation, soil texture, minerals, climate etc. (USDA, 2014).

Soils of Kuttanad shows seasonal fluctuations in electrical conductivity due to saline water intrusion. From the present study it was observed that the mean values for EC of soils in the study area varied from 0.36 to 0.88 dS m^{-1}. About 98.67 per cent of soils reported EC value less than 1 dS m^{-1} and 1.33 per cent of samples recoded EC value greater than 1 dS m^{-1} (Fig 14). The highest mean value for EC was recorded from Purakkad (0.88 dS m^{-1}) and this might be due to the nearness to sea and ingress of saline water during summer. Similar findings were reported by Beegum (2016). The highest values for EC was recorded during summer months (Kurup and Aiyer. 1973).

Modaihsh *et al.* (1989) studied the effect of elemental sulphur on chemical changes and nutrient availability in soils and reported that soil acidity and EC of soil was increased by the addition of sulphur to the soil. In the present study a significant positive correlation between EC and available suphur (0.635**) also implies a similar effect.

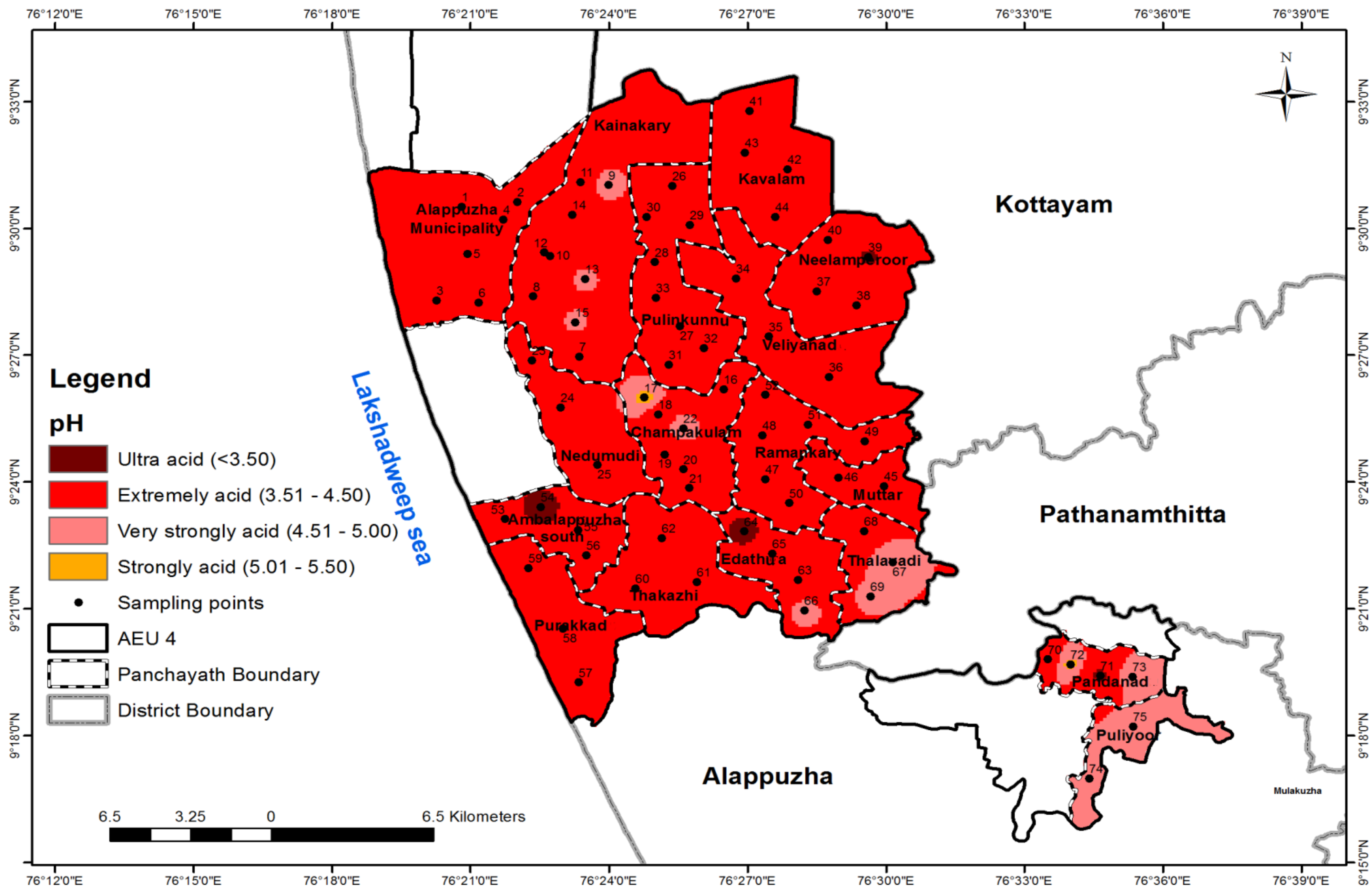

Fig. 12 Spatial distribution of soil pH in the post flood soils of AEU4 in Alappuzha district

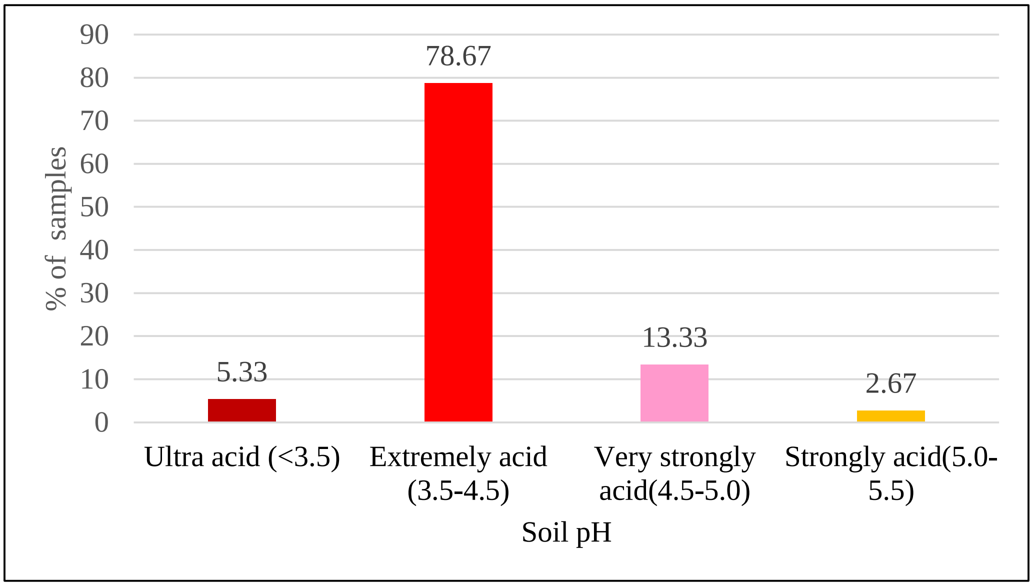

Fig.13 Frequency distribution of soil pH in the post flood soils of AEU 4 in Alappuzha district

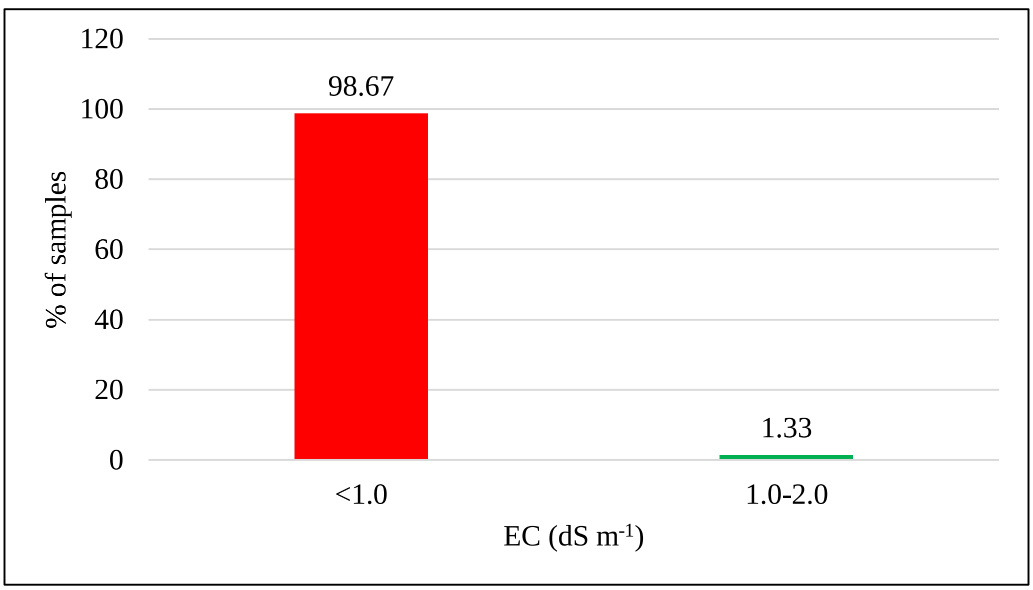

Fig.14 Frequency distribution of soil EC in the post flood soils of AEU 4 in Alappuzha district

5.1.2.3 Organic carbon content

Kuttanad soils are rich in organic carbon content due to the presence of woody matter which are at various stages of decomposition that are embedded in the soils. From the present study it is observed that organic carbon content in the study area are in high range and the mean values ranged from 1.88 (Alappuzha Municipality) to 5.39 per cent (Neelamperoor). The post flood soil samples from the different regions of Alappuzha district (AEU 4) had reported an increase in the organic carbon levels. Since all the sampling points are lower than the other regions of the state, the tendency of flood water was to flow towards the western region to empty out its contents which might have deposited organic sources at these sites. The apparent build-up of organic carbon in soil can only be justified through such a natural process (KSBB, 2019)

From the Fig.17, it is observed that nearly 94.67 per cent of soils had organic carbon content greater than 1.5 per cent in contradiction to pre-flood data where only 69.94 per cent of soils were reported high in organic carbon content (Appendix IV). The enhanced rate of carbon sequestration as reported from flooded rice soils is due to lower rate of decomposition under anaerobic environment (Lal, 2004).

From the present study a significant positive correlation was found between soil organic carbon and clay content (0.606**) which implies that soil organic carbon content increases with clay content. Hoyle *et al.* (2011) also reported that clay content is a key determinant of soil to explain its capacity to store organic carbon and its ability increases with increase in clay content. More over under anaerobic flooded conditions the rate of decomposition of organic matter is slower than under oxidized aerobic environment resulting in wider C : N ratio at equilibrium.

Grybos *et al.* (2009) opined that low pH favors low oxidation of organic carbon leading to its excessive accumulation, which corresponds to high organic carbon in Kuttanad soil. Generally organic carbon content in Kuttanad soils are high due to the presence of decomposed, partially decomposed and undecomposed organic matter and organic carbon content in soil ranged from 2.79 to 7.70 per cent (Kannan *et al.,* 2014).

Kuttanad was severely affected by flood during 2018 and the land gets fertilized by organic materials which get deposited and increase organic carbon content in the soil. The highest value for organic carbon content is recorded in Neelamperoor which might be due to the low pH (3.54), richness in organic matter debris and higher clay content.

5.1.2.4 Available nitrogen

In the study area, the available nitrogen content in the soil showed wide variation and the mean values were ranged from 188 kg ha^{-1} to 602 kg ha^{-1}. The highest mean value was reported in Veliyanad (602 kg ha^{-1}) and the lowest in Puliyur (188 kg ha^{-1}). About 69.34 per cent of soils reported to be medium in available nitrogen status whereas 9.33 and 21.33 per cent of samples had high and low nitrogen content respectively (Fig.18).

A significant positive correlation reported between available nitrogen content and organic carbon in the present study (r = 0.626**). The highest available nitrogen status in Veliyanad panchayat may due to high organic carbon content (4.42 per cent). Even though organic carbon content in the soil is high, most of the soil samples showed low and medium fertility status for available nitrogen. The available nitrogen content in the soil depends on the mineralisation of nitrogen in soil which is the function of soil microbes such as ammonifiers and nitrifiers whose activity is restricted under submerged condition and low pH (Liji, 1987). This might be the reason for low and medium status of available nitrogen in the study area.

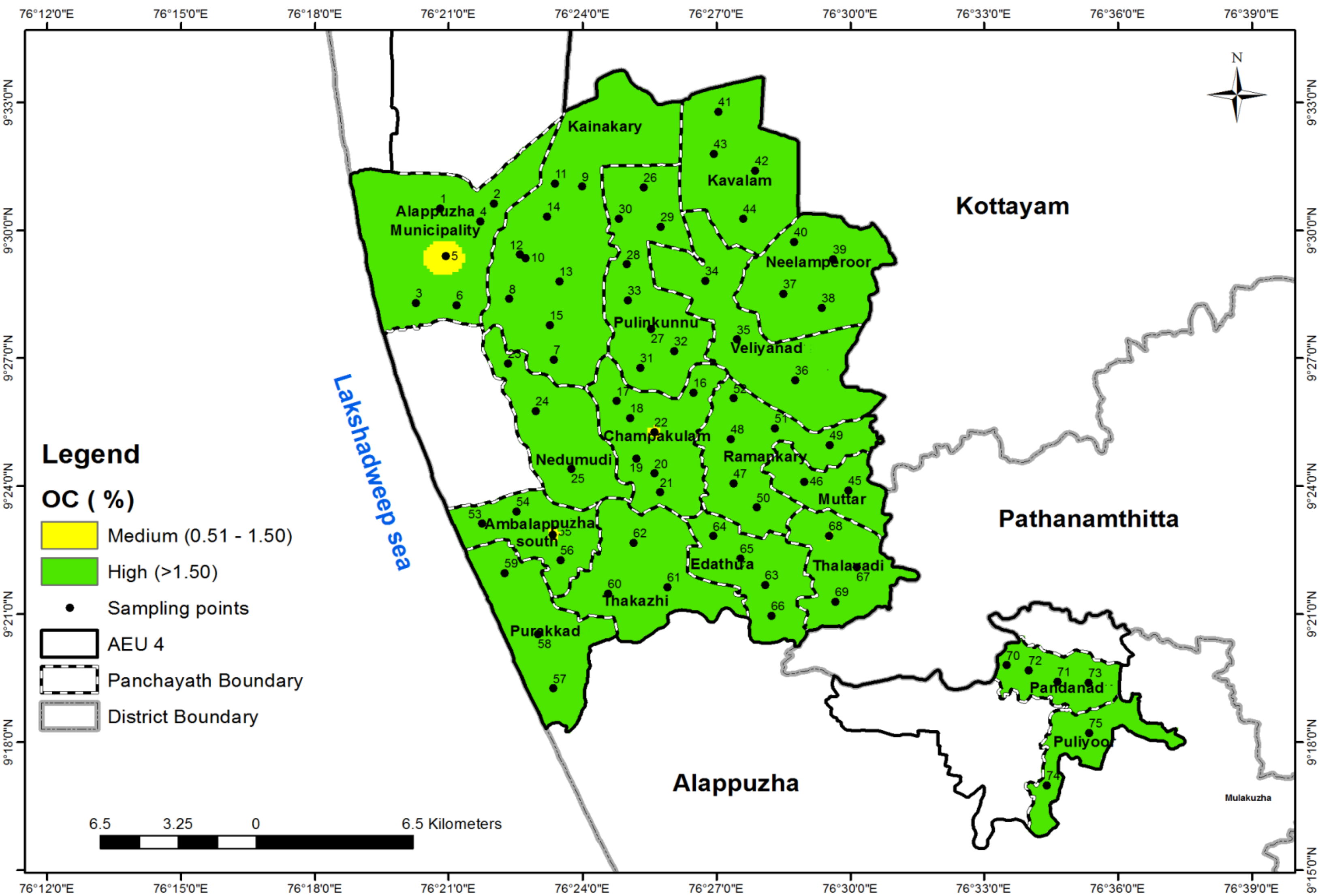

Fig. 15. Spatial distribution of organic carbon content in the post flood soils of AEU 4 in Alappuzha district

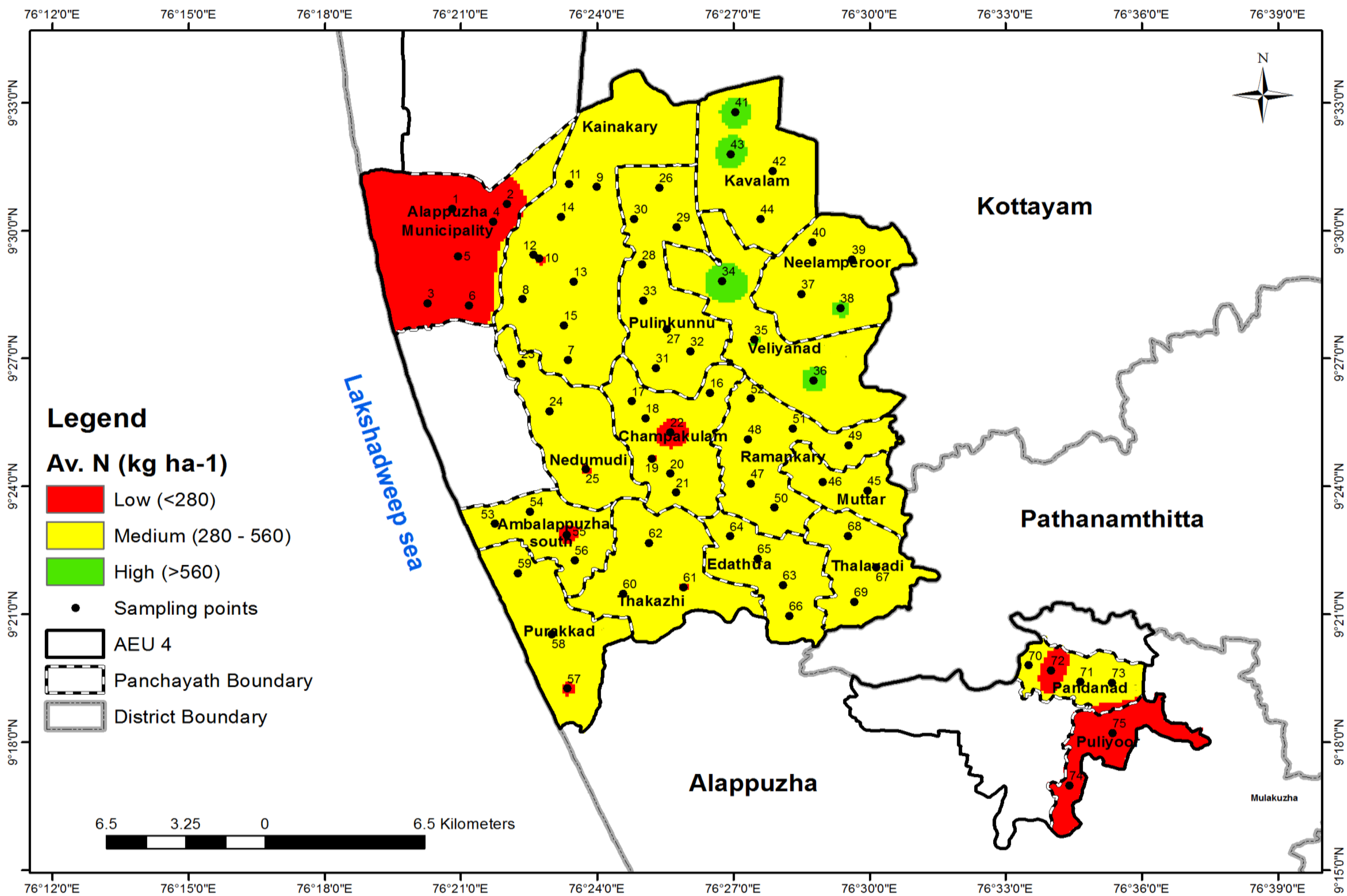

Fig. 16. Spatial distribution of available nitrogen content in the post flood soils of AEU4 in Alappuzha district

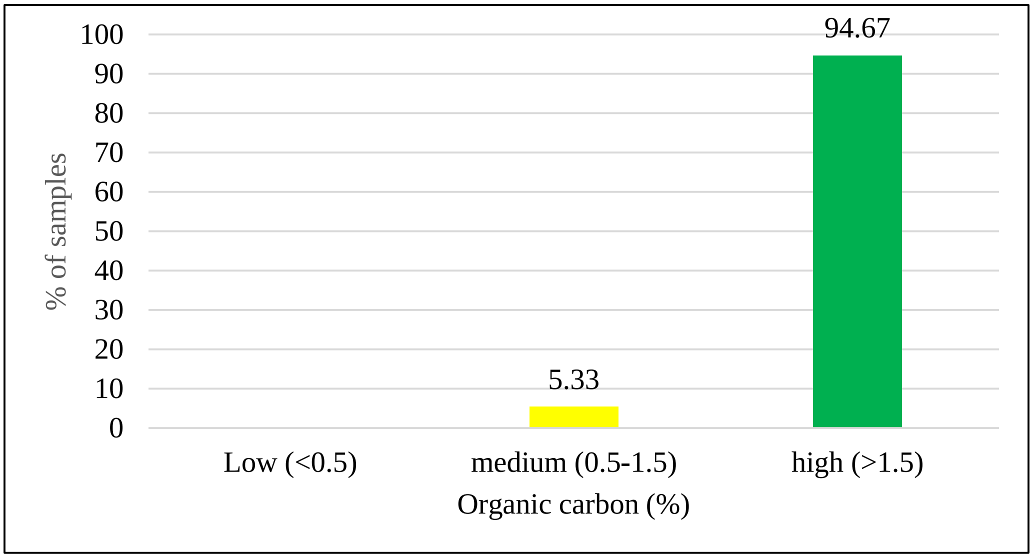

Fig.17 Frequency distribution of organic carbon content in the post flood soils of AEU 4 in Alappuzha district

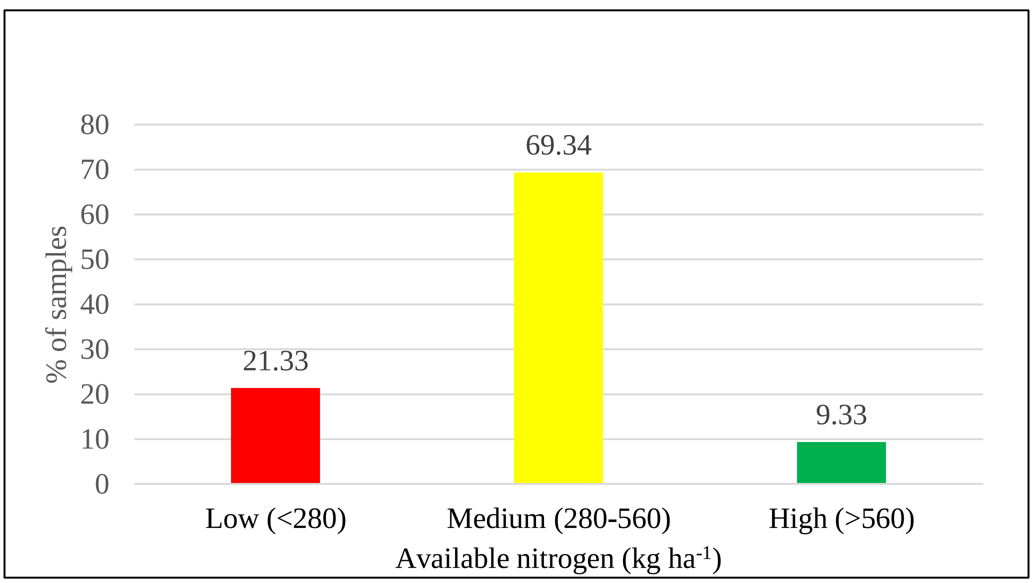

Fig.18 Frequency distribution of available nitrogen content in the post flood soils of AEU 4 in Alappuzha district

5.1.2.5 Available phosphorus

Phosphorus is one of the essential plant nutrient that affects plant metabolism. From the study, it is observed that the available phosphorus content in the study area showed wide variation. Mean values for available phosphorus in the study area varied from 5.79 kg ha^{-1} to 24.2 kg ha^{-1}. The highest mean value for available phosphorus was recorded from Ambalappuzha South panchayat (24.2 kg ha^{-1}) and the lowest value was observed in Muttar (5.79 kg ha^{-1}). 67.06 per cent of soils were high and 18.65 per cent of soils were medium in available phosphorus in the pre-flood scenario (Appendix IV) but the available phosphorus content in the soil decreased after flood and about 48 per cent of soil samples recorded low status for available phosphorus and 34.67 per cent were medium and only 17.33 per cent of soils were high in available phosphorus (Fig.21).

In general the availability of phosphorus content in most of the soils were low to medium in the present study. This may be due to the fixation of phosphorus in the soil by Fe and Al ions which are predominant in acid soils. Phosphorus fixation in Kuttanad soils are attributed by the presence of kaolinite clay in soil coupled with precipitation of phosphorus with iron and aluminium due to high Fe and Al oxides in soil (Beegum, 2016). High phosphorus content in Ambalappuzha South may be due to the over fertilization and addition of enormous quantities of manures.

The higher the soil acidity, the larger the immobilization of phosphorus added in soils. A non-significant but positive correlation existed between available phosphorus and soil pH in the present study (0.157). Change in available nutrient contents was related with fertilizer applications, which were also influenced by soil properties. The growth of aquatic plants for a long time during the flooding might be major reason for the lower phosphorus content in the Kuttanad soil (Richardson, 1985).

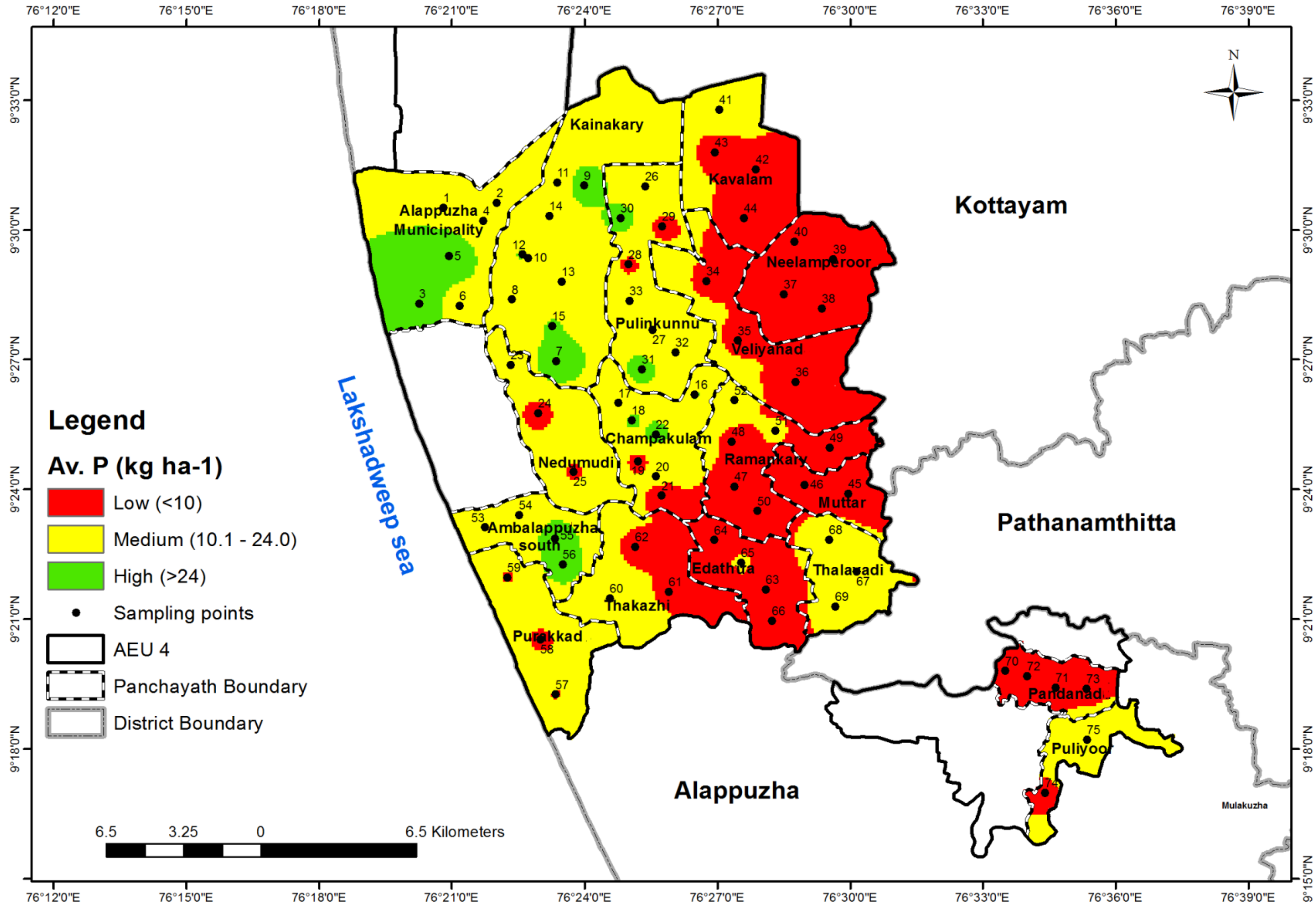

Fig. 19. Spatial distribution of available phosphorus content in the post flood soils of AEU 4 in Alappuzha district

5.1.2.6 Available potassium

In general the status of available potassium content in the post flood soils of AEU 4 in Alappuzha district was medium to high. The mean values for available potassium ranged from 252 kg ha^{-1} to 672 kg ha^{-1}. The highest mean value for available potassium was recorded from Purakkad (672 kg ha^{-1}) and lowest was recorded from Puliyur which was 252 kg ha^{-1}.

In the present study as inferred from Fig. 22, 24 per cent of soils were in medium range and 22 per cent were in low range in potassium availability. About 76 per cent of soils were reported to have high potassium status which is in contradiction to the pre-flood data where 57.59 per cent soils reported medium status in available potassium and only 20.41 per cent of soil reported high available potassium content (Appendix IV).

The study area is subjected to saline water intrusion during summer season. This can be one of the major reason that can be attributed for high potassium status. High incorporation of paddy straw to soil, high organic carbon content, low pH coupled with saline water intrusion may be the reason for high potassium content in the study area (Nath, 2016).

Thafna *et al.* (2017) reported that soil organic matter play a major role in holding and supply of potassium and the application of rice straw significantly increase available K content in soil. Beena (2005) also reported that the available potassium content of Kuttanad soils ranged from 142.1 to 326.4 mg kg^{-1} and the higher values might be due to high incorporation of paddy straw in the region. The findings are similar with findings of Ponnamperuma (1972), who reported that the high potassium content in soil might be by the addition of organic manures and amendments in the soils.

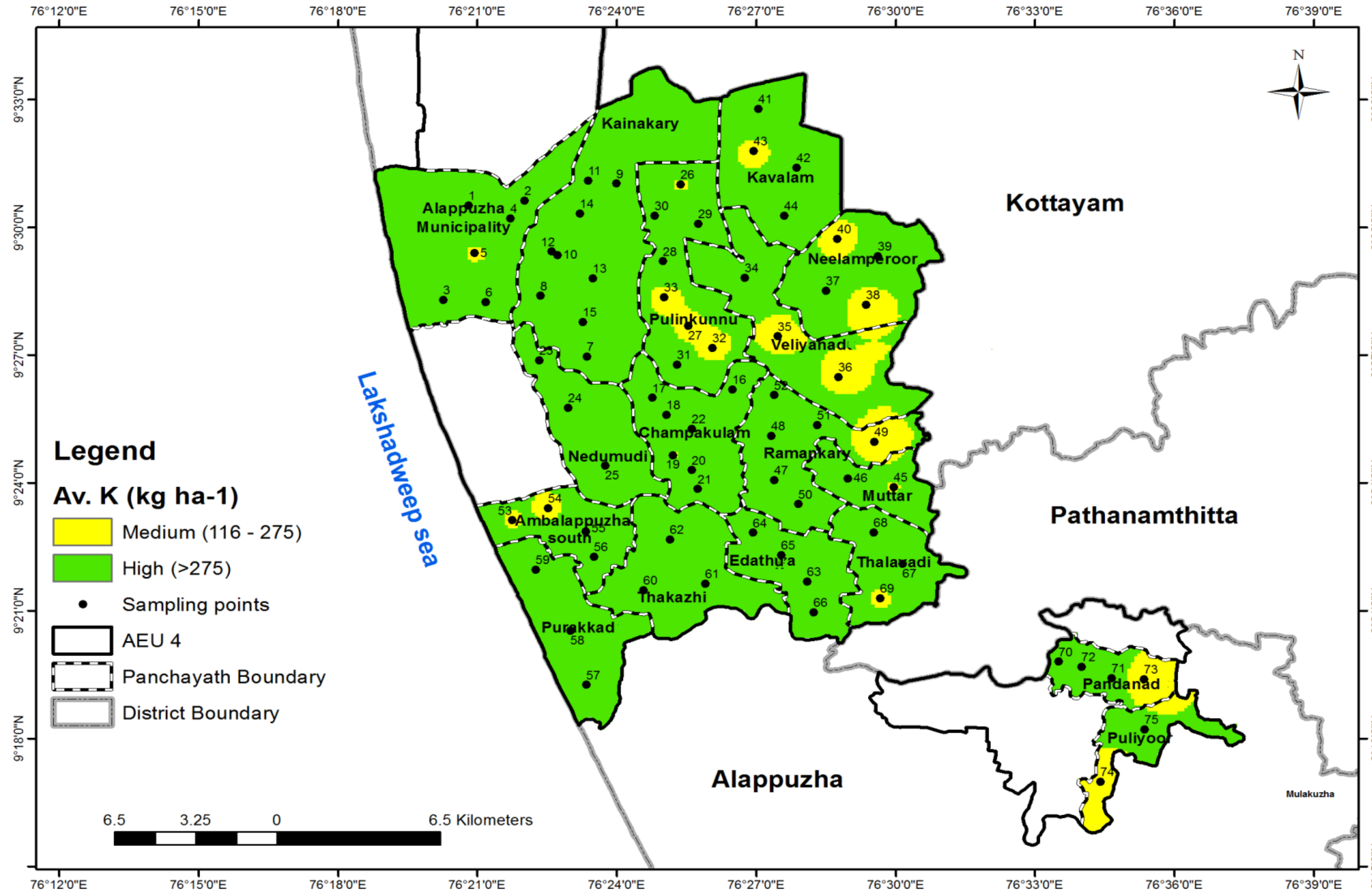

Fig. 20. Spatial distribution of available potassium content in the post flood soils of AEU 4 in Alappuzha district

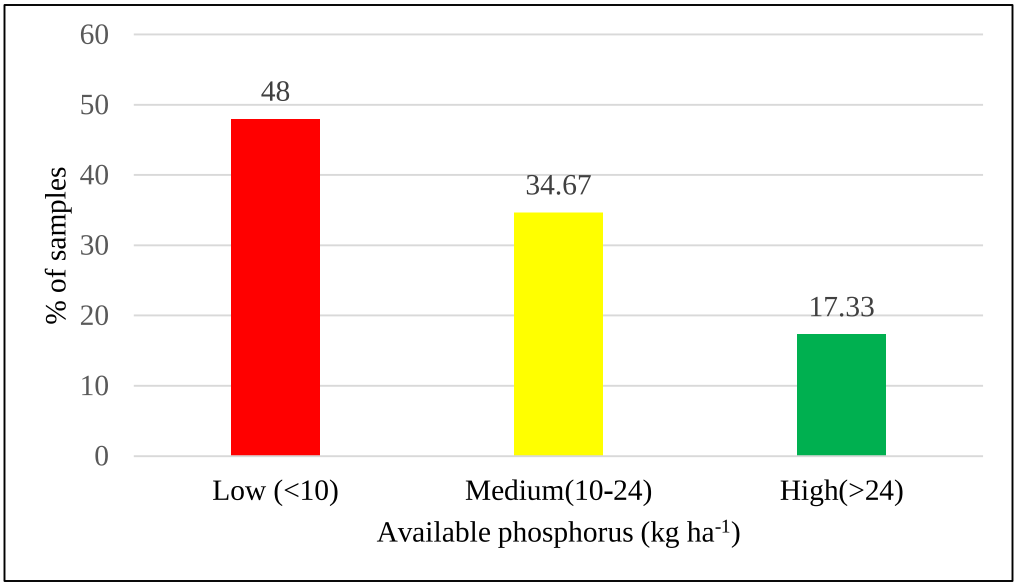

Fig.21 Frequency distribution of available phosphorus content in the post flood soils of AEU 4 in Alappuzha district

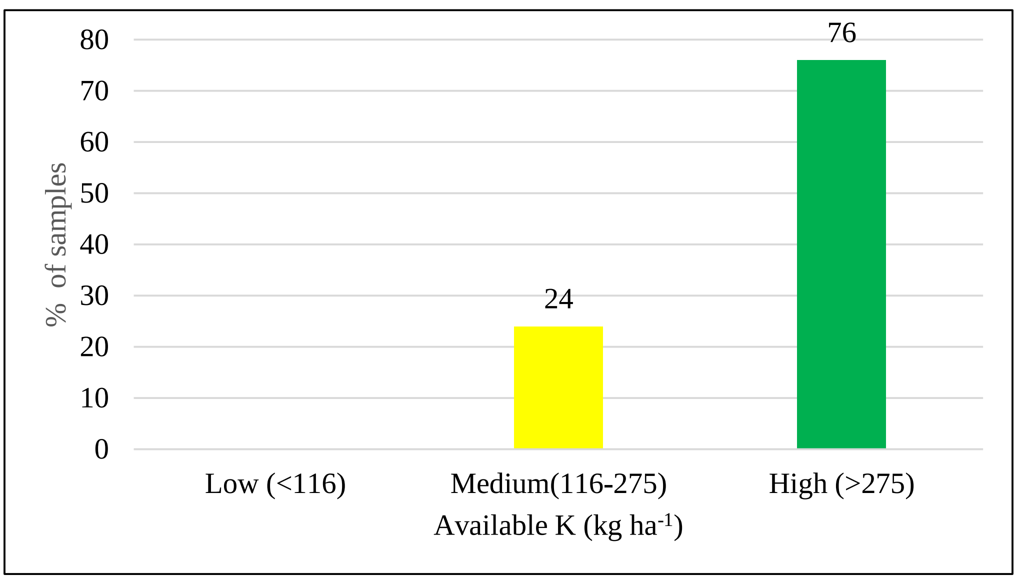

Fig.22 Frequency distribution of available potassium content in the post flood soils of AEU 4 in Alappuzha district

5.1.2.7 Available calcium

From the study conducted, it is observed that the available calcium content in entire study area belonged to sufficient status (>300 mg kg^{-1}) and a positive correlation is exhibited with electrical conductivity (r = 0.282*) (Fig.25). This increased available calcium content in these soils in general might be attributed to the higher amount of calcium present soils with the application of liming materials.

The mean values of available calcium content in the soil ranged from 460 mg kg^{-1} to 913 mg kg^{-1} and entire samples are sufficient in available calcium which is in contradiction with pre-flood condition where only 22 per cent of soil were sufficient in available calcium content (Appendix IV). Deposition of sediments followed by the flood had a positive impact on available calcium content in soil by increasing its concentration High calcium content in the soils might be attributed by deposition of marine deposits and saline water intrusion coupled with the effect of liming material amendment in soil (Nath, 2016).

5.1.2.8 Available magnesium

The available magnesium content in the soils of AEU 4 in Alappuzha district ranged from 226 to 634 mg kg^{-1} and exhibited a significant positive correlation with electrical conductivity. The highest magnesium content was recorded in Kainakary (634 mg kg^{-1}) and lowest magnesium content was observed in Pandanad (226 mg kg^{-1}). The available magnesium was deficient in 99.88 per cent of soils in the pre-flood situation (Appendix IV) but there was an increase in available magnesium content in Kuttanad soils followed by flood and 98.66 per cent of samples were found to be sufficient in magnesium (Fig. 26). Similar results were reported by Suswanto *et al.* (2007), Shamshuddin *et al*. (2015), and Castro *et al.* (2016) who observed that application of ground magnesium limestone containing Mg increased the availability of magnesium. Sediment deposition by flood, saline water intrusion coupled with the effect of lime material amendment in soil might be the reason for high magnesium availability in Kuttanad soils (Nath, 2016).

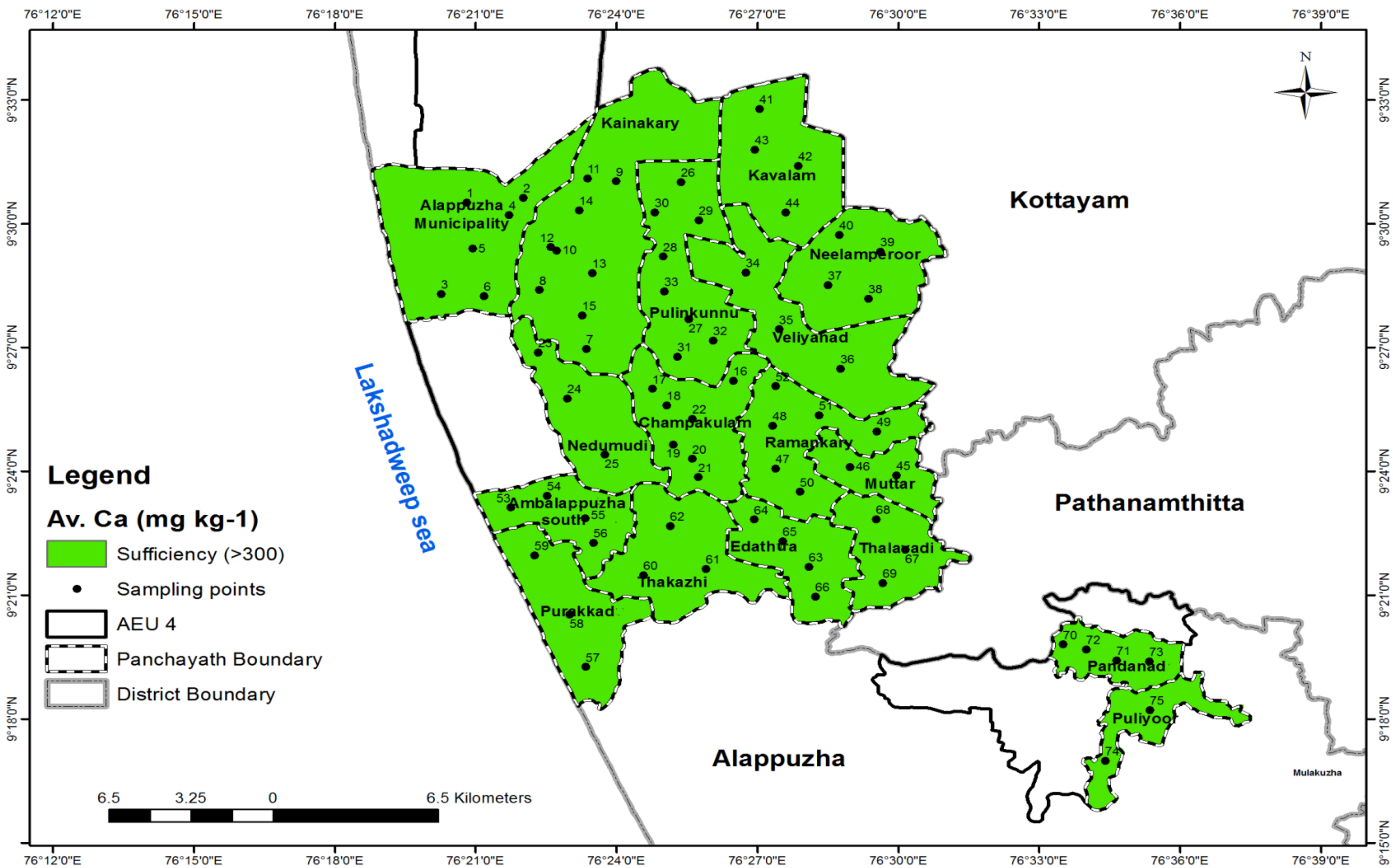

Fig. 23. Spatial distribution of available calcium content in the post flood soils of AEU 4 in Alappuzha district

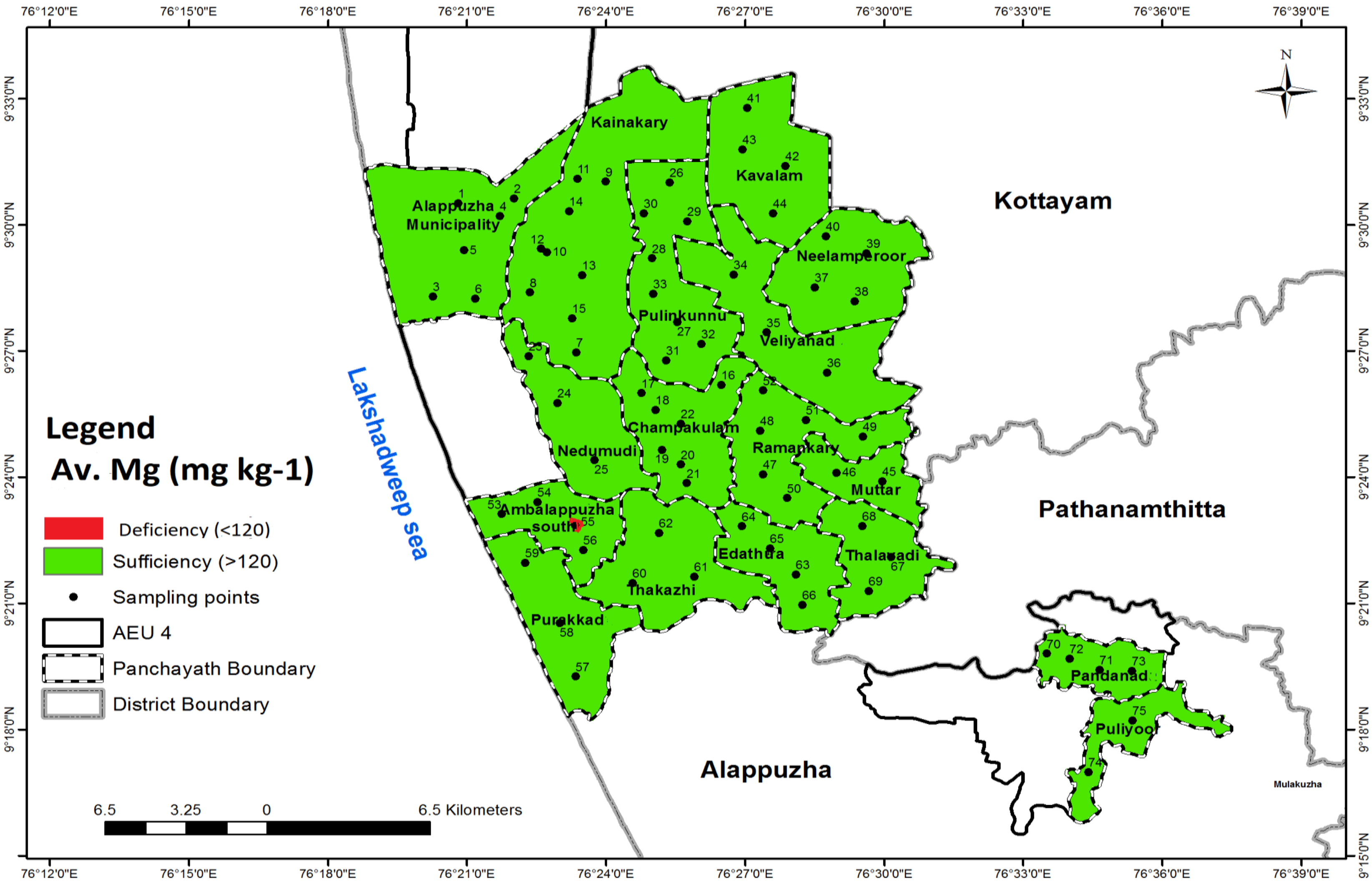

Fig. 24. Spatial distribution of available magnesium content in the post flood soils of AEU4 in Alappuzha district

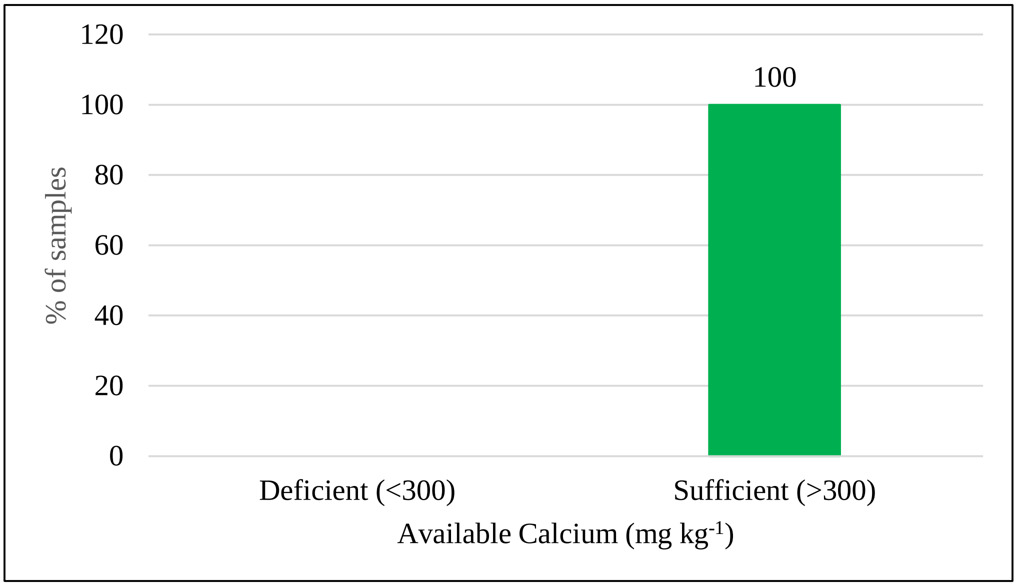

Fig.25 Frequency distribution of available calcium content in the post flood soils of AEU 4 in Alappuzha district

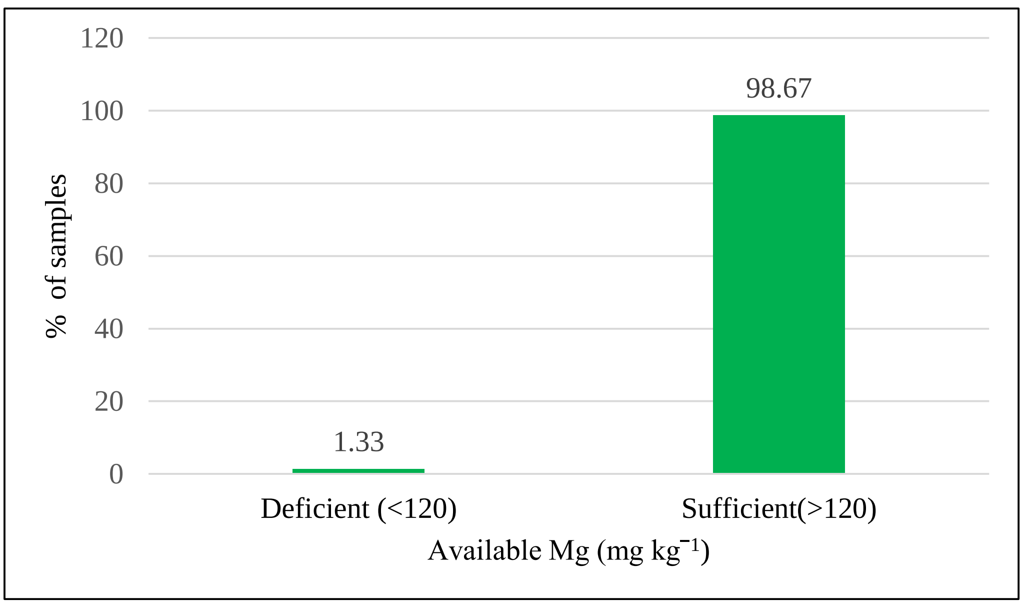

Fig.26 Frequency distribution of available magnesium content in the post flood soils of AEU 4 in Alappuzha district

5.1.2.9 Available sulphur

The soils of Kuttanad are rich in available sulphur content due to the presence of iron sulphide minerals which on oxidation produce sulphuric acid and contributing to low pH (Kurup and Aiyer, 1973). From the study it is observed that the available sulphur content in post flood soils of AEU 4 in Alappuzha district were high and ranged from 81.2 to 1144 mg kg^{-1} and 100 per cent of soils were sufficient in available sulphur status. The highest value for available sulphur was reported in Neelamperoor where organic carbon content recorded the highest value (1144 mg kg^{-1}). The high status of available sulphur content may be attributed to jarosite minerals. Similar results were reported by Cicy in 1989 who opined that the soils of Kuttanad contained large amount of water soluble S, the mean value being 126.6 ppm. While the value ranged from 25 to 395 ppm. Water soluble S was negatively correlated with pH and positively correlated with EC and organic carbon. In the present study, available sulphur was negatively correlated with soil pH (-0.735**) and positively correlated with electrical conductivity (0.635**) and organic carbon content (0.314**). On comparing availability of sulphur content in pre-flood soils, there was not significant increase in sulphur content as 94.53 per cent of soils were sufficient in sulphur content before flood (Appendix IV).

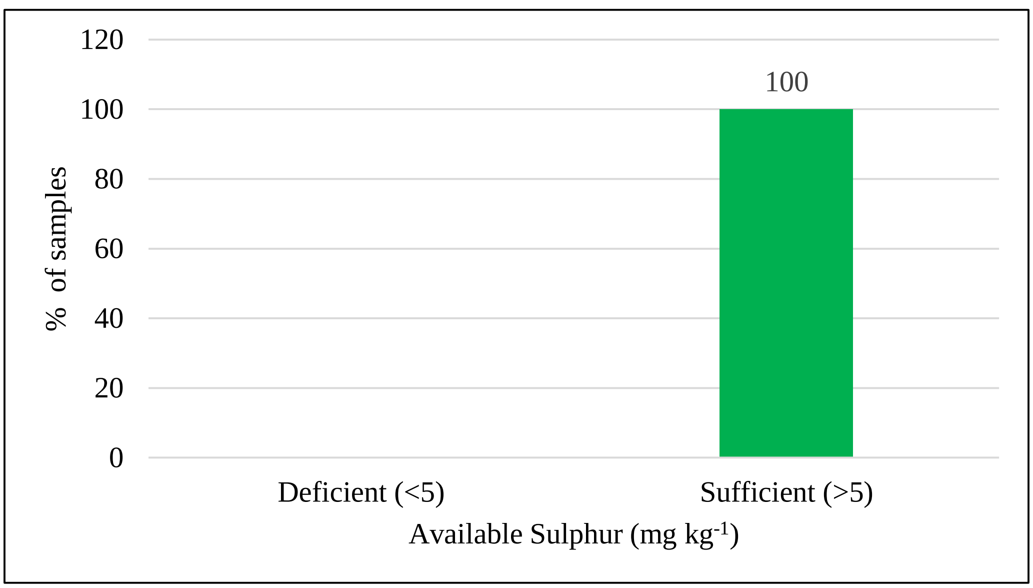

Fig.27 Frequency distribution of available sulphur content in the post flood soils of AEU 4 in Alappuzha district

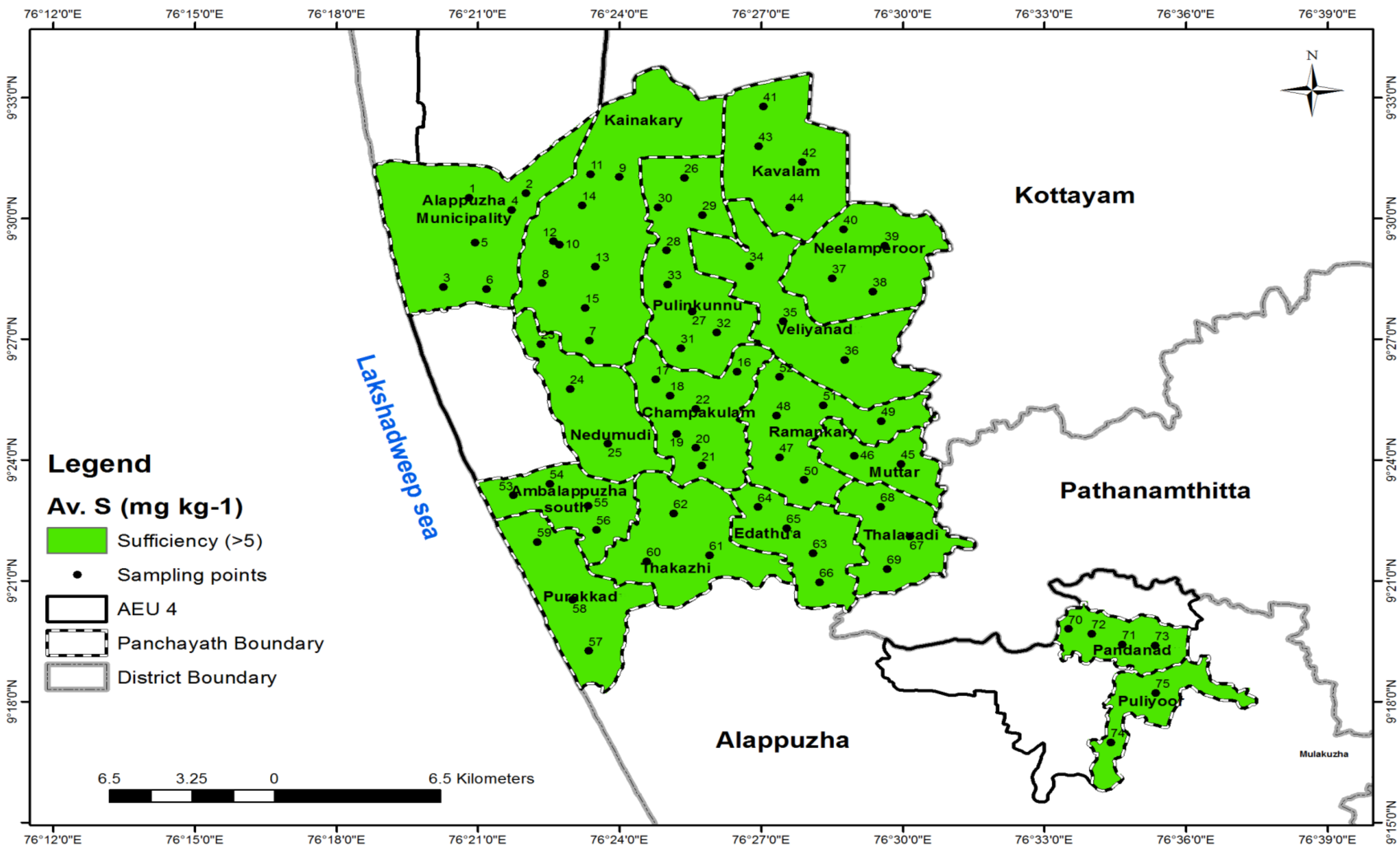

Fig. 28. Spatial distribution of available sulphur content in the post flood soils of AEU4 in Alappuzha district

5.1.2.10 Available boron

The available boron content was deficient in most of the samples and mean values for available boron ranged from 0.06 to 0.38 mg kg^{-1}. In pre-flood situation boron was found to be sufficient in 40.06 per cent of soils in the study area but flood had resulted in lowering the boron status in the soil and found to be deficient for 93.33 per cent of soils (Appendix IV, Fig. 29).

Mengel *et al. (*2001) reported that solubility of boron is high in low pH. High intensity rainfall will lead to loss of soluble forms of boron by leaching. This might be the reason for deficiency of boron in the post flood soils of AEU 4 in Alappuzha district.

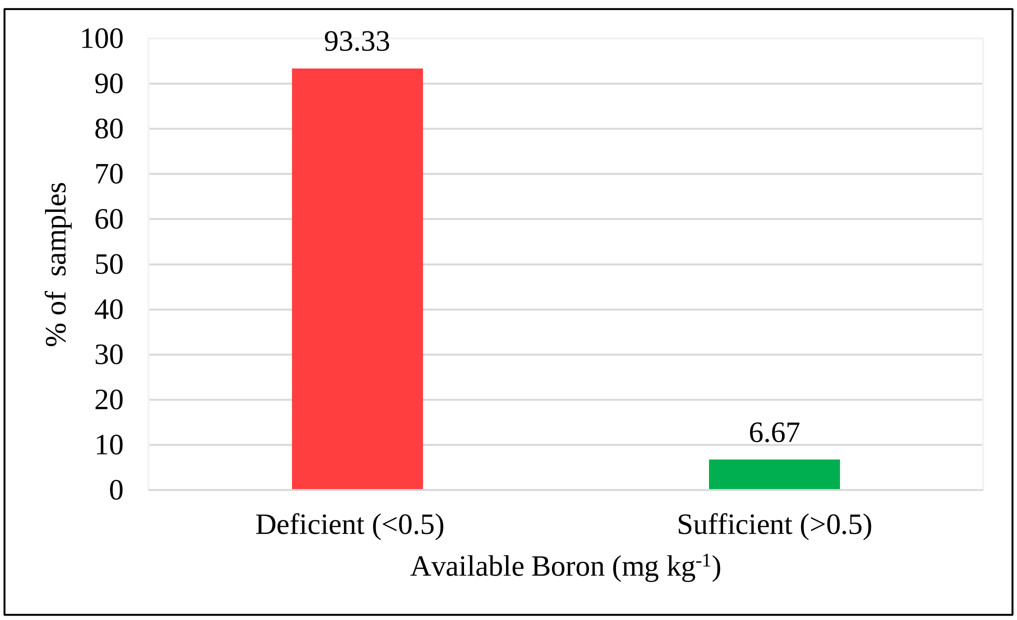

Fig. 29 Frequency distribution of available boron content in the post flood soils of AEU 4 in Alappuzha district

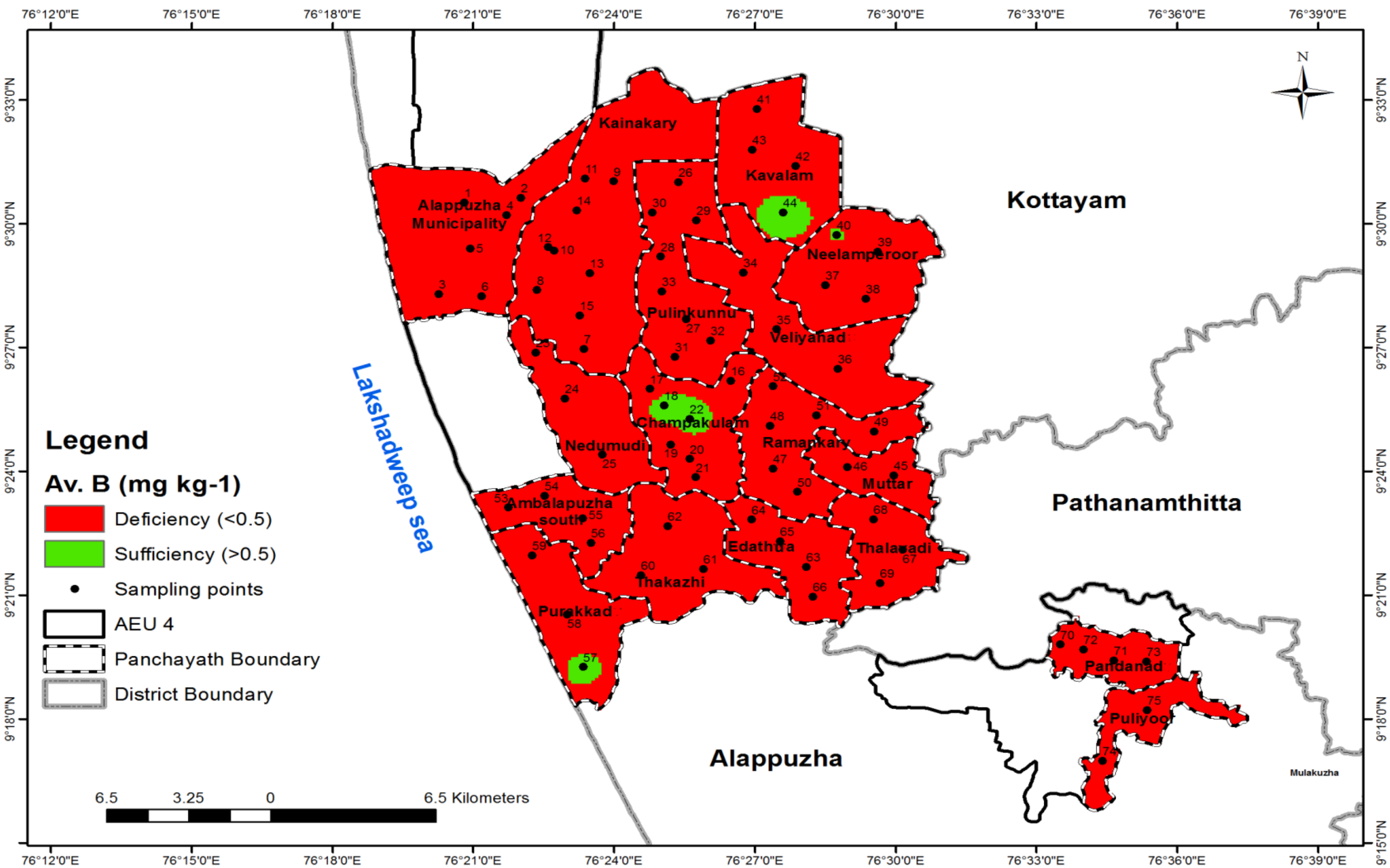

Fig. 30. Spatial distribution of available boron content in the post flood soils of AEU 4 in Alappuzha district

5.1.3 Biological properties

5.1.3.1 Acid phosphatase

Acid phosphatase catalyse non-specific hydrolysis of inorganic phosphate in pH ranging from 4 to 6 and plays an important role in the supply of phosphate to the plants (Tabaldi *et al.*, 2007). The conversion of organic phosphates to inorganic P is catalysed by phosphatase enzyme. (Miller *et al.*, 2001)

From the study it is understood that significant variation existed in the activity of acid phosphatase. The mean values varied from 13.9 to 59.2 µg of p-nitrophenol released g^{-1} soil h^{-1} (Table 15). From the Fig.31, it is observed that about 41.33 per cent of samples were in the range of 10 to 25 and 25 to 50 µg of p-nitrophenol released g^{-1} soil h^{-1}.

In general an inverse relationship between available P and acid phosphatase activity was noticed. The highest activity of acid phosphatase noticed in these areas might be attributed to the low available P status. Versaw and Harrison (2002) reported that whenever there is a signal indicating P deficiency in the soil, acid phosphatase secretion in soil is increased to enhance the solubilisation and remobilization of PO_4 and influence the ability to cope up with P stressed condition.

In the present study also the same principle is noticed where the highest value for acid phosphatase activity was recorded from Veliyanad panchayat (59.2 µg of p-nitrophenol released g^{-1} soil h^{-1}) with low phosphorus content (7.56 kg ha^{-1}.). While the lowest value was reported in Ambalappuzha South (13.9 µg of p-nitrophenol released g^{-1} soil h^{-1}) where the available phosphorus content was the highest (24.2 kg ha^{-1}). These results corroborated with the findings of Dick and Tabatabai (1993). A significant negative correlation (Table 25) between available phosphorus and acid phosphatase activity (-0.275*) in the present study also confirms the results. A similar result was reported by Nath (2016) where the activity of acid phosphatase is high in Thakazhi where the available P content was comparatively low (7.04 kg ha^{-1}). This finding might be due to the highest microbial phosphorus solubilizers count that might have helped in the solubility of P sources and increasing the availability of substrates for the enzyme to act upon.

Kalembasa and Kuziemska in (2010) also opined that organic content in soil has been resulting in significant increase in the activity of phosphatase. A high value organic carbon in Veliyand (4.42 per cent) confirms the aforesaid result. Hence the role of organic carbon in increasing the acid phosphatase activity cannot be evicted.

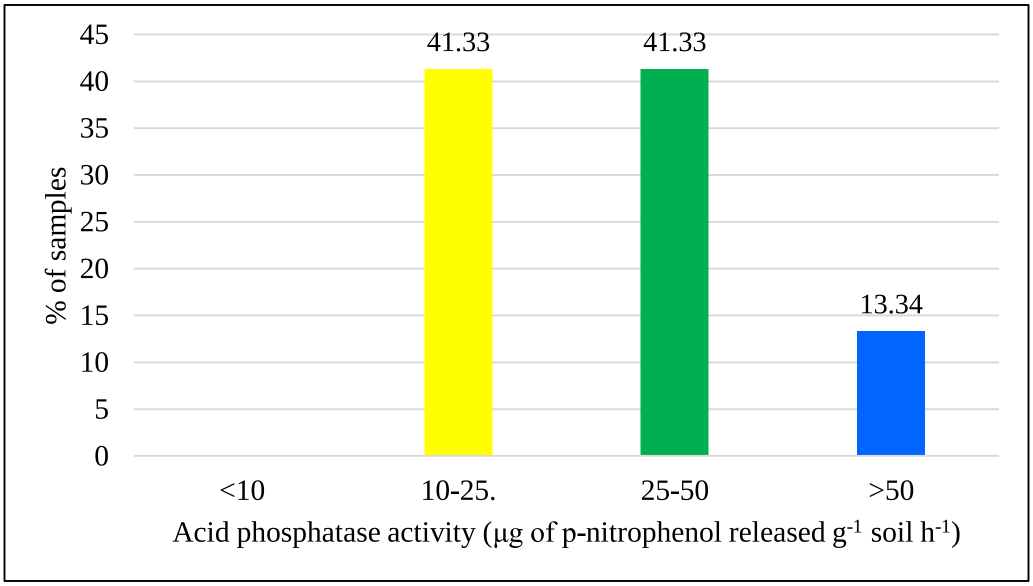

Fig.31 Frequency distribution of acid phosphatase activity in the post flood soils of AEU 4 in Alappuzha district

5.2 SOIL QUALITY INDEX

Soil quality is a complex functional concept, which cannot be measured directly but can be inferred from soil characteristics and cultivation practices. Soil Quality Index (SQI) is considered as the most appropriate for quantitative assessment of soil quality. Soil quality depend on a variety of factors which includes soil type, land management practices and inherent soil characteristics (Stott *et al.*, 2013; Hammac *et al.*, 2016). A holistic dataset of soil quality indicators should include physical, chemical and biological properties (Dick, 1994; Doran and Zeiss, 2000). Takoutsing *et al.* (2016) focused on chemical and biological properties because they were considered as the most important factors that have been reported to be affected by land management while they have a great impact on crop productivity. In the context of current climate change, the main aim of this study was to investigate how soils with previous history of flooding respond and recover from an extreme flood event and how the flooding affects the soil quality.

A weighted soil quality index was worked out for the study area by creating minimum dataset (MDS). Principal component analysis (PCA), a data reduction tool was used to select the most appropriate indicator(s) to represent and estimate SQI. In the present study**,** out of 20 attributes, eleven were selected for MDS and soil quality was evaluated by providing appropriate weightage and scores for the selected attributes. Relative soil quality index (RSQI) was used to categorize soils to good, medium and low quality. From the Fig 32, it is observed that nearly 81.33 per cent of soils were good in soil quality while the remaining 18.67 per cent were medium in soil quality.

The soil quality index was found to be the highest with Veliyand (306) which also reported the highest value for RSQI (76.7 per cent) while the lowest value for RSQI was reported in Puliyur (65.2 per cent).

The highest index in Veliyanad might be attributed to the favourable content of selected MDS parameters *viz.,* sand content (soil texture), organic carbon content, per cent of water stable aggregates, available magnesium, porosity, pH, acid phosphatase, EC, available calcium, potassium and boron in soil that contributed to the SQI. This is evident from the results of the soil samples analyzed for these parameters. Low RSQI in Puliyur is due to the low status attributed by the parameters retained in the MDS.

Extreme flood events are predicted to have a negative impact on soil quality as the flood water remain on the land for several weeks or months (Natural England 2014). Another fact is almost all of the soil physical, chemical and biological quality indicators studied might have undergone reversible changes, returning back to the normal levels within weeks of floodwater removal. Silt and clay deposits contributed by flood water might have increased the soil quality of the study area.

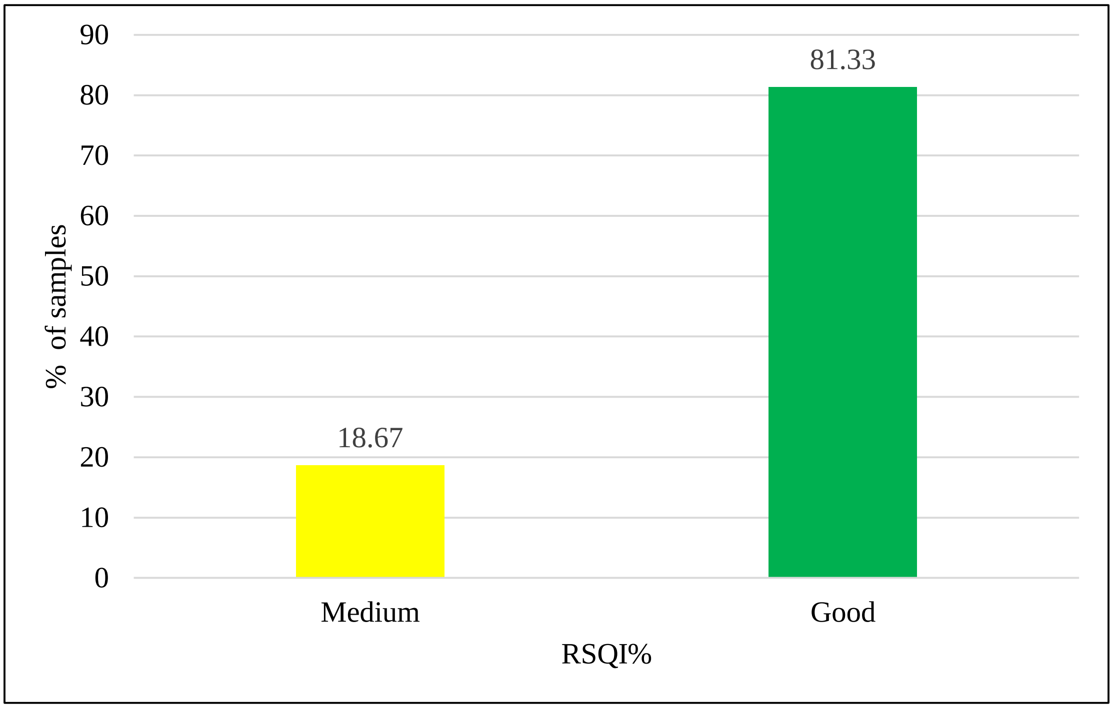

Fig.32 Frequency distribution of RSQI in the post flood soils of AEU 4 in Alappuzha district

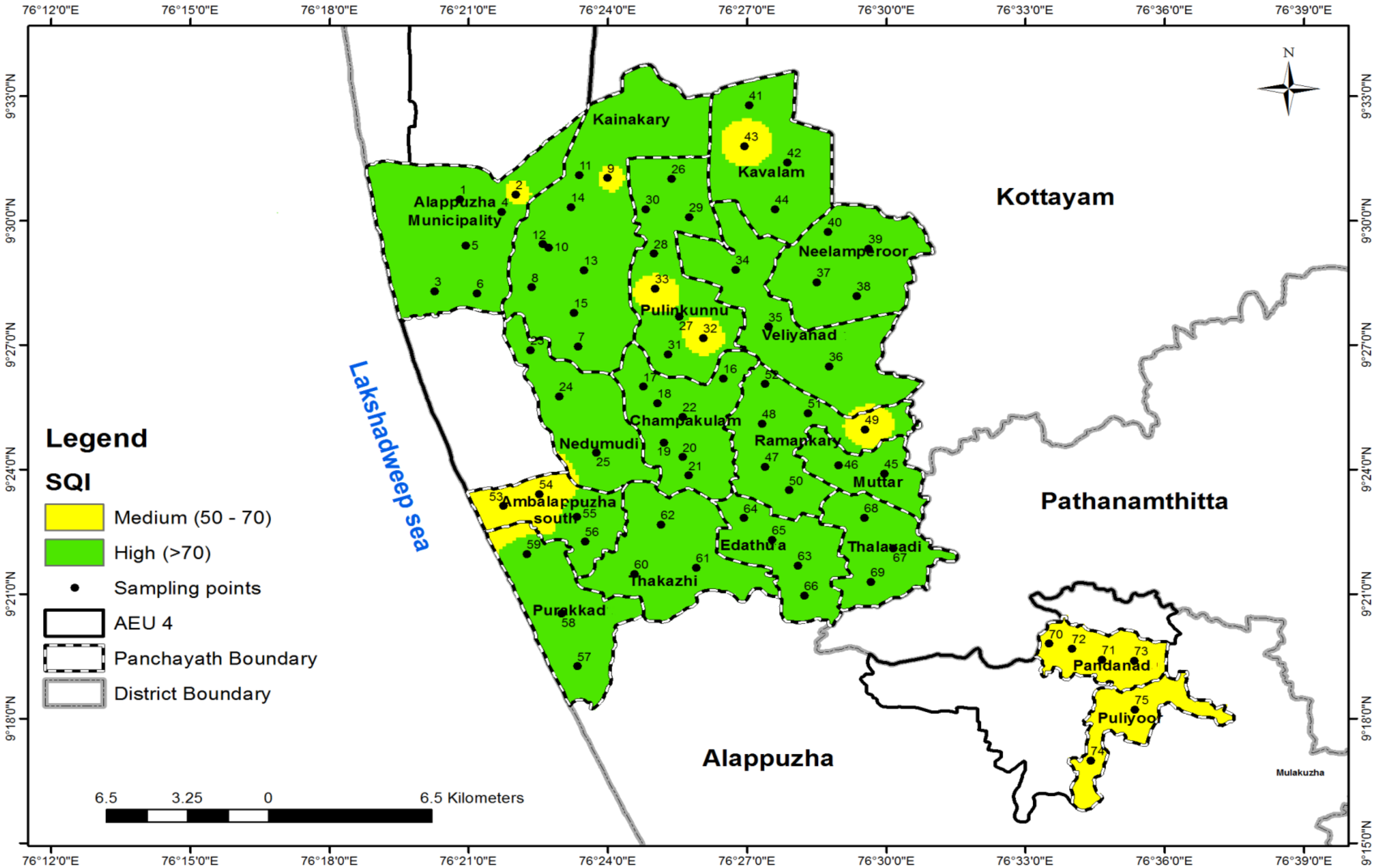

Fig.33 Spatial distribution of SQI in the post flood soils of AEU 4 in Alappuzha district

5.3 NUTRIENT INDEX (N.I)

Soil nutrient index evaluate the fertility status of soils based on the samples in each of the three classes, *i.e.*, low, medium and high. Nutrient index (NI) for organic carbon, available nitrogen, phosphorus and potassium were worked out using the equation formulated by Parker and modified by Ramamurthy and Bajaj (1969). Nutrient index value for organic carbon recorded maximum value (3.00) in all panchayats except Alappuzha Municipality, Champakulam, Ambalappuzha South and Thalavadi as all the samples recorded high value for organic carbon content.

Nutrient index for available nitrogen recorded the highest value (3.00) in Veliyanad as all the samples were high in available nitrogen and lowest value was recorded from Alappuzha Municipality and Puliyur as all the samples collected were in low nitrogen status.

Highest value for nutrient index for available phosphorus was recorded from Kainakary as all the samples had high available phosphorus content and lowest index value was recorded from Veliyanad, Neelamperoor, Muttar, Ramankary, Purakkad, Edathua and Pandanad as the soil samples collected from these panchayats were low in available phosphorus content.

N.I value for available potassium in soil belonged to high status in all panchayats and the maximum value of N.I for available potassium was observed in Nedumudi, Purakkad, Thakazhi and Edathua.

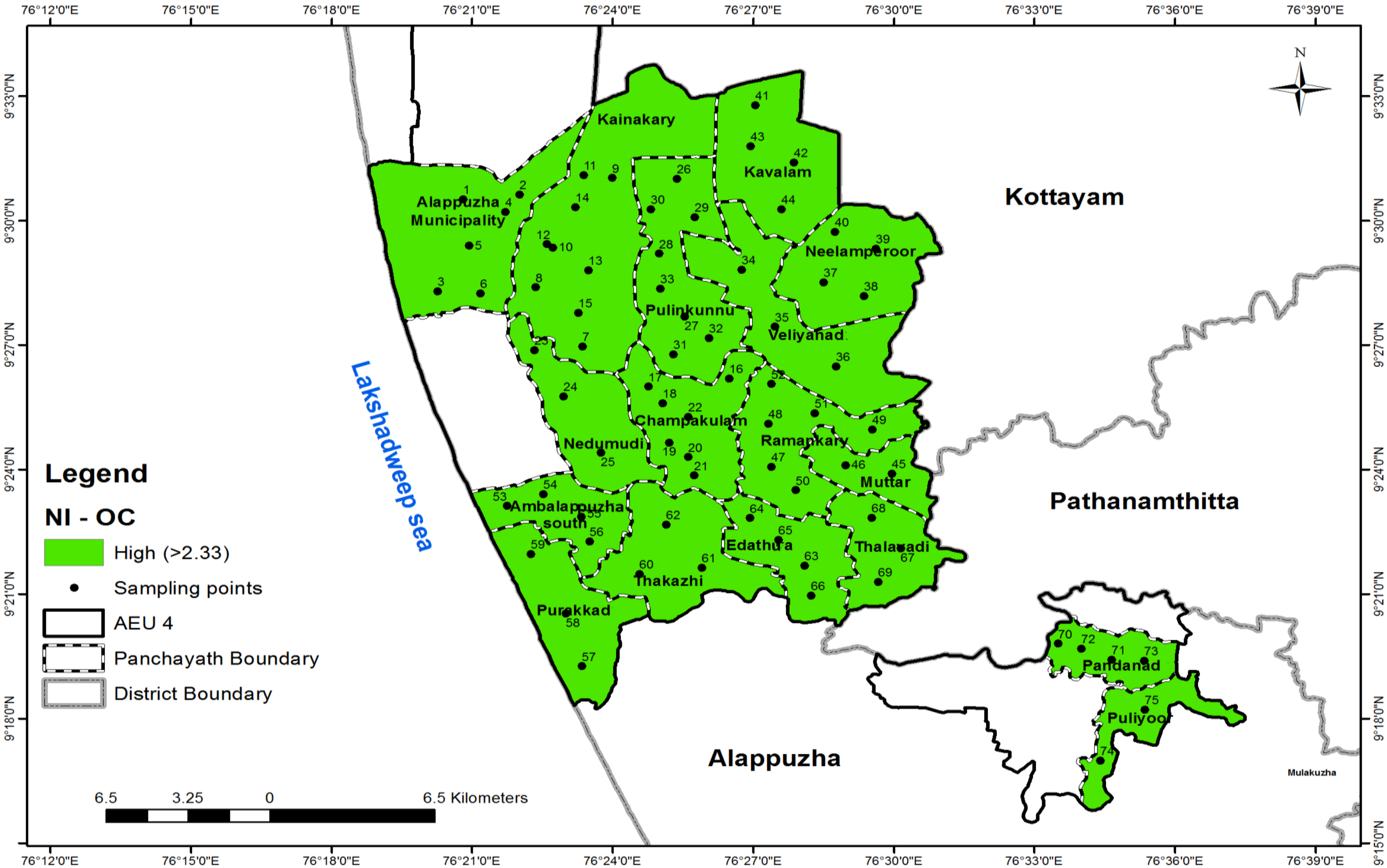

Fig.34 Spatial distribution of N.I for organic carbon content in the post flood soils of AEU 4 in Alappuzha district

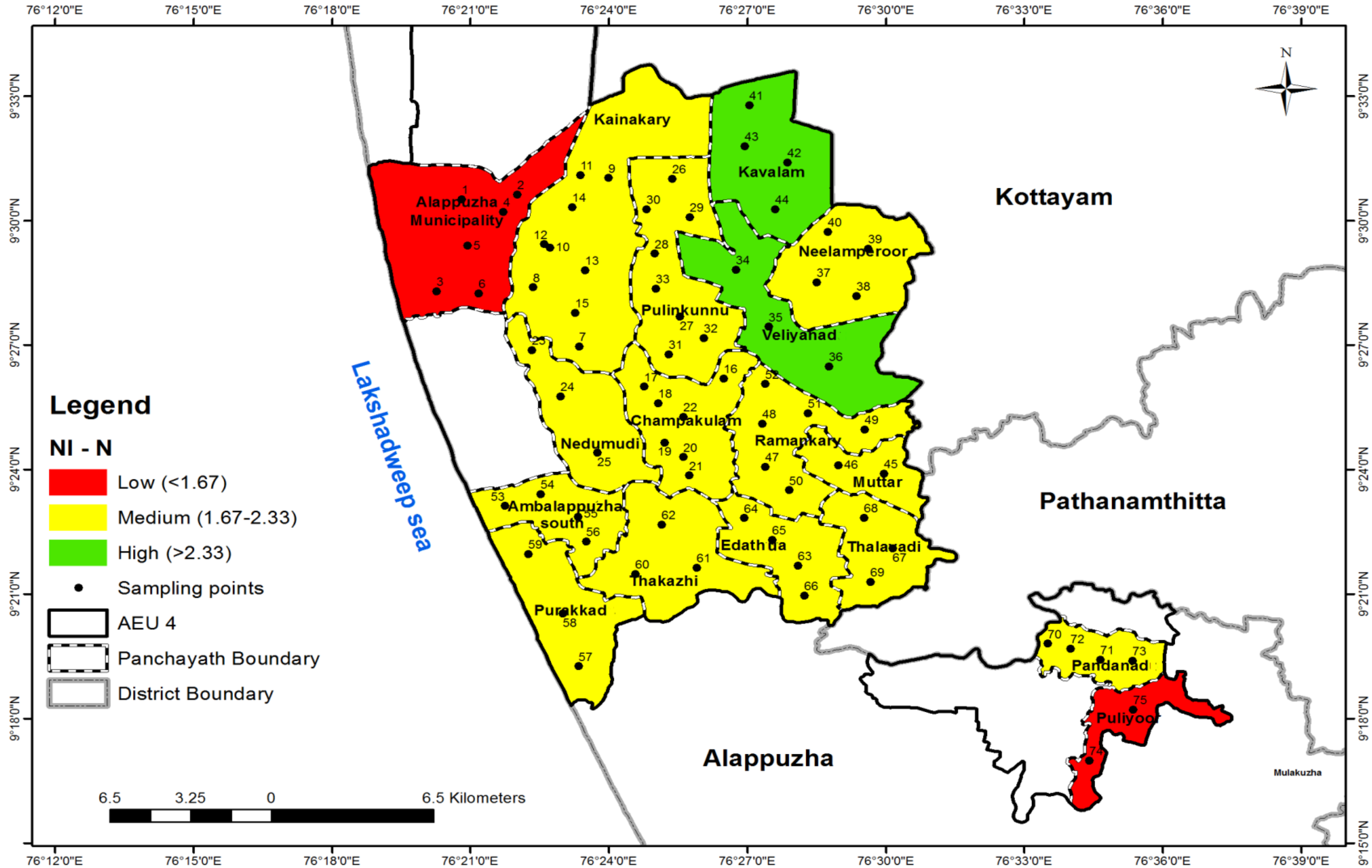

Fig.35 Spatial distribution of N.I for available nitrogen in the post flood soils of AEU 4 in Alappuzha district

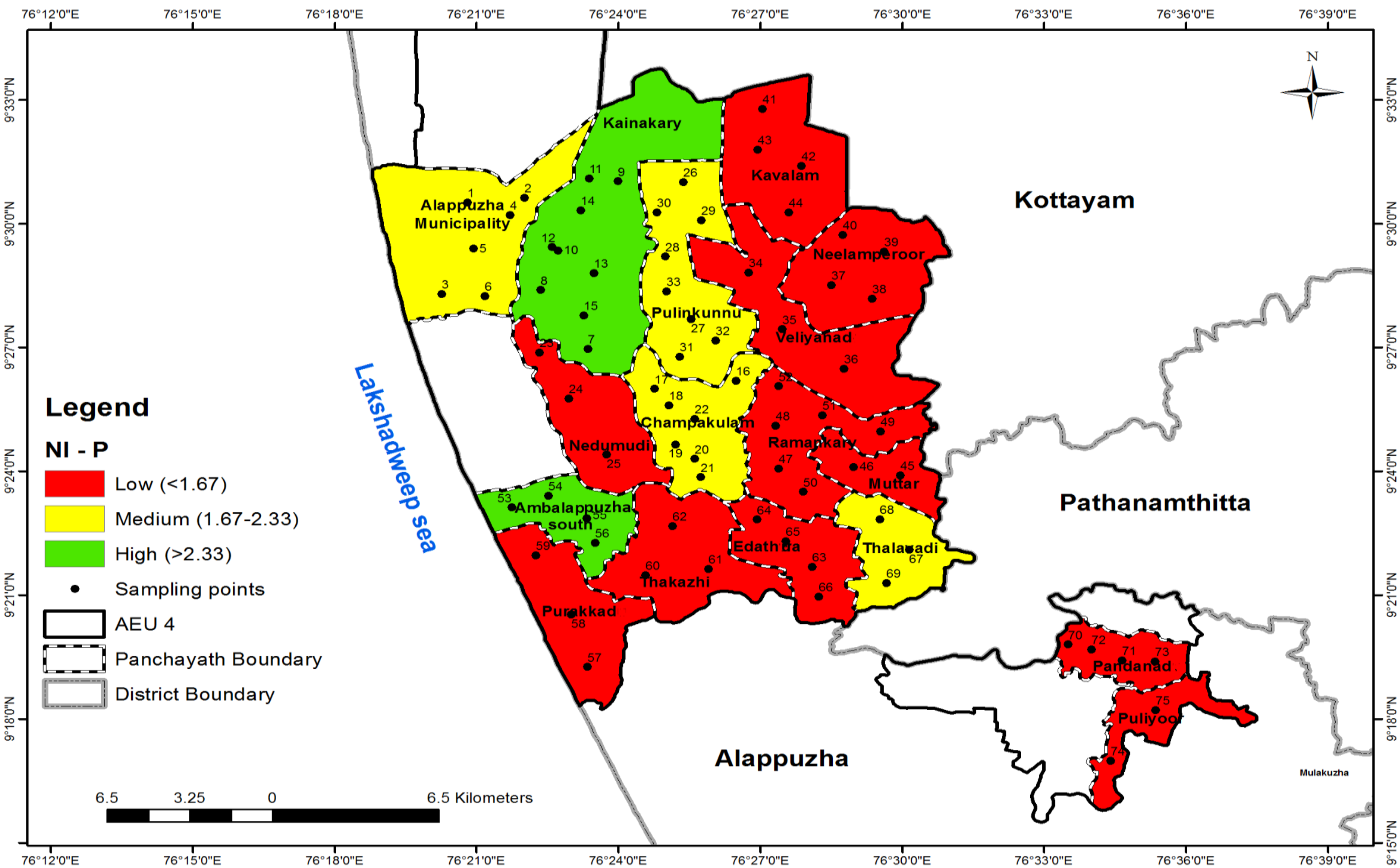

Fig.36 Spatial distribution of N.I for available phosphorus in the post flood soils of AEU 4 in Alappuzha district

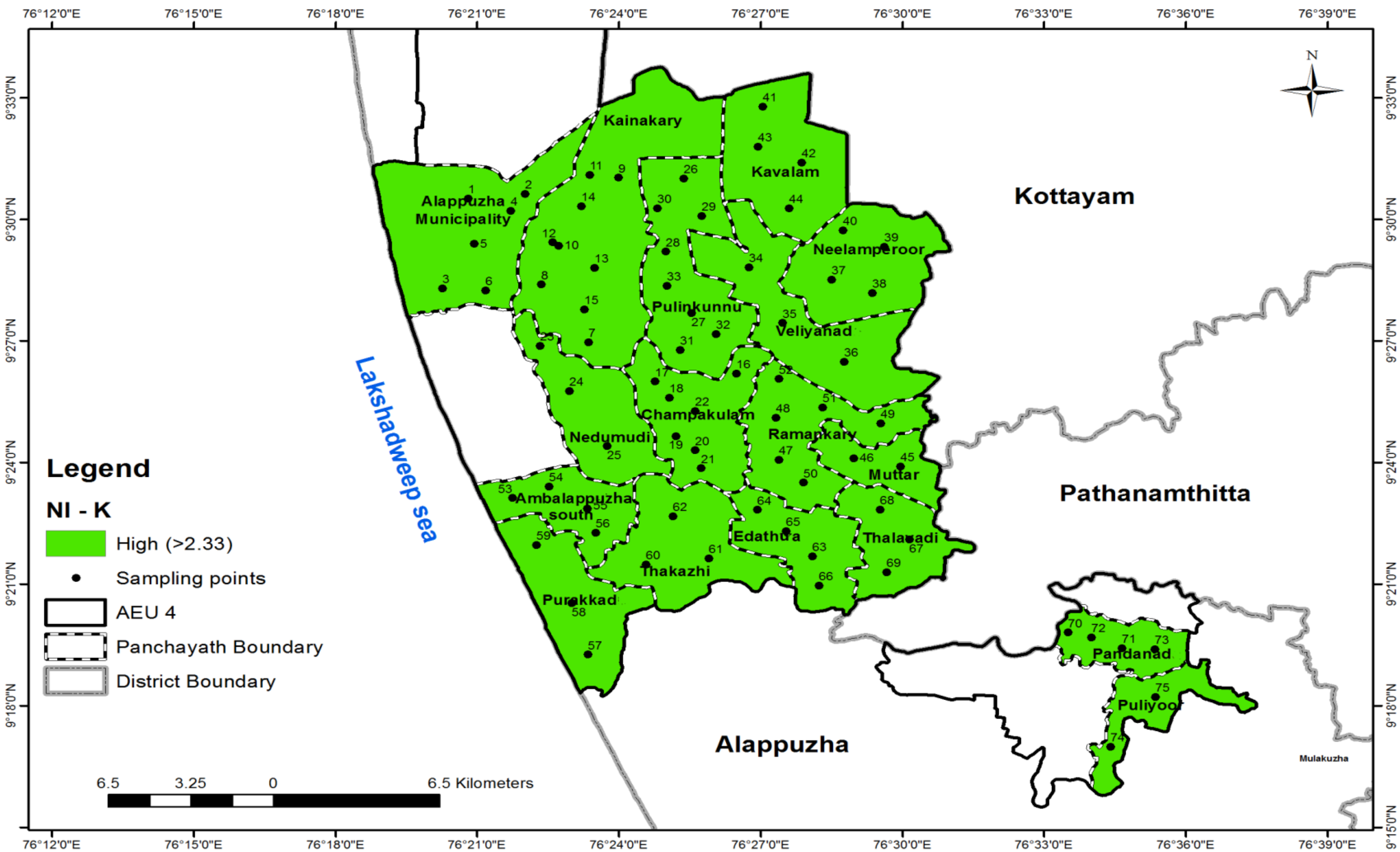

Fig.37 Spatial distribution of N.I for available potassium in the post flood soils of AEU 4 in Alappuzha district

5.4 LAND QUALITY INDEX (LQI)

Achieving and maintaining land quality is an essential step to sustaining agricultural production in an environmentally safe manner. Land quality index reveals the quality of the soils for agricultural use. Among various land quality indicators, soil organic carbon (SOC) stocks is the most reliable indicator for monitoring land degradation and quality (Kumar and Jhariya, 2015).

The SOC content was high in surface soils and ranged from 1.88 to 5. 39 per cent. The high organic carbon content in the surface layer might be due to slow decomposition rate and high biomass addition. The highest SOC stock was observed in Purakkad (8.39 kg m^{-2}) which is attributed by the high organic carbon content (5.30 per cent). The factors which influence LQI are soil bulk density and organic carbon content. The lowest value for LQI was reported from Puliyur where soil organic carbon content was 1.89 per cent. LQI for 62.67 per cent of the samples were in the range 3 to 6 (low), 22. 66 per cent in medium and only 14.67 per cent of soils belonged to very low category. The variation in estimated SOC stocks was due to difference in organic carbon content in the sampling sites and low bulk density.

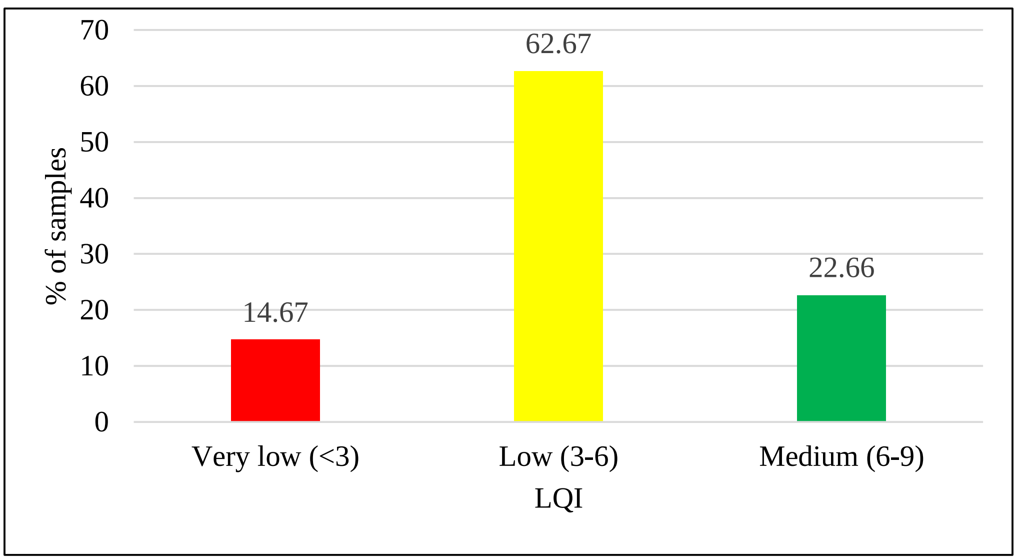

Fig.38 Frequency distribution of LQI in the post flood soils of AEU 4 in Alappuzha district

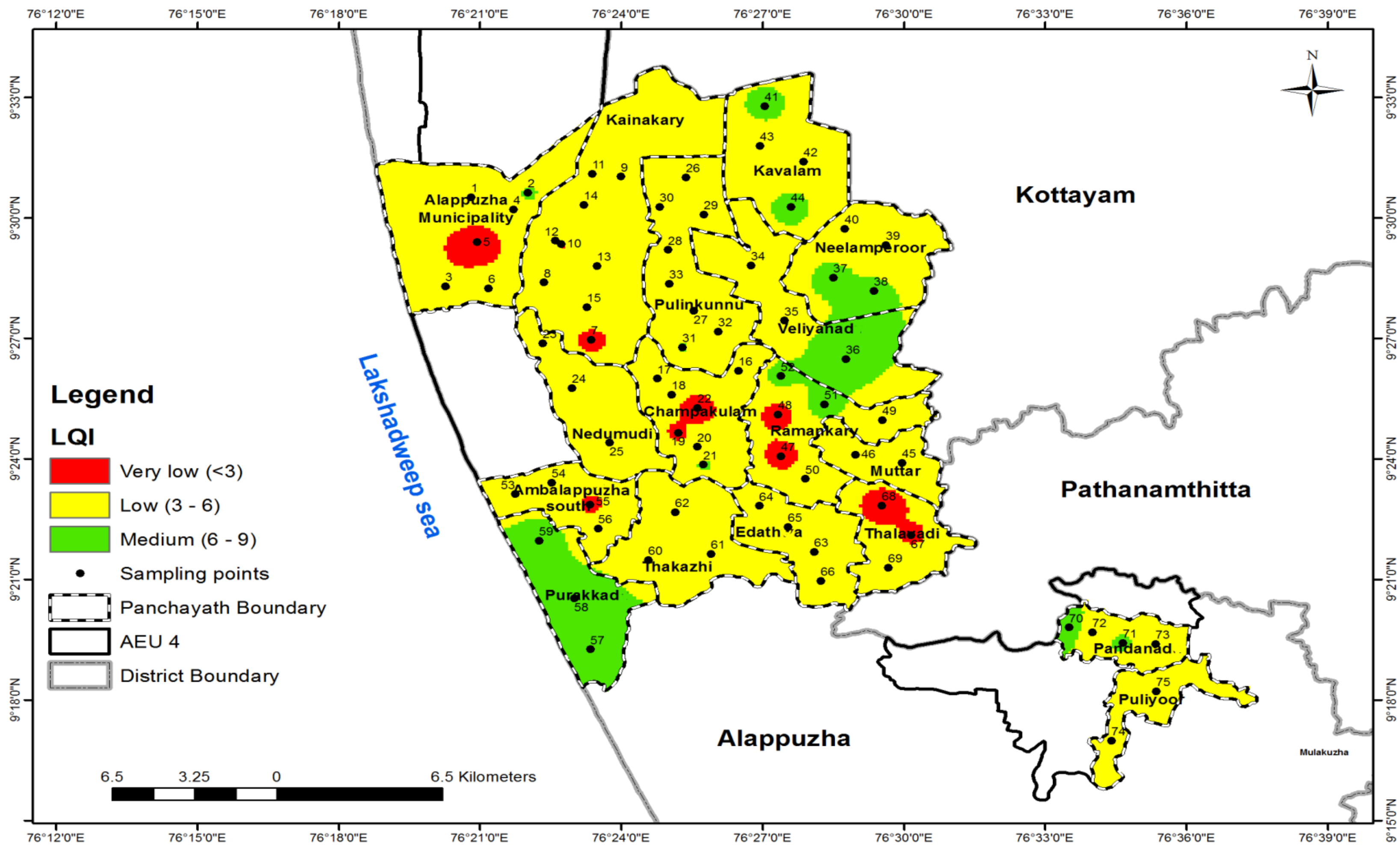

Fig. 39. Spatial distribution of land quality index in the post flood soils of AEU 4 in Alappuzha district

5.5 COMPARISON OF PRE AND POST-FLOOD SOIL FERTILITY STATUS OF AEU 4 OF ALAPPUZHA DISTRICT

The results of the analysis of the chemical parameters in the post flood soils were compared with the pre-flood nutrient status data of the AEU 4 reported by Kerala State Planning Board, 2013 (Appendix IV).

In the pre-flood scenario, 21 per cent of the soils belonged to extremely acidic class, 24.76 per cent in very strongly acidic, and 25.47 per cent in strongly acidic class in contradiction to post flood status where 78.67 per cent of soils belonged to extremely acidic class. This clearly indicates an increase in soil acidity of the Kuttanad soils after the flood. Organic carbon status of the study area had been increased after the flood as 94.67 per cent of samples reported a high status for organic carbon in contradiction to pre-flood data where only 64.29 per cent of soils showed high status. This might be due to the deposition of organic matter rich sediments in the study area (GOK, 2018b).

Depletion in the status of phosphorus and boron has been observed in the study area. About 54.67 per cent of soils were low in phosphorus in post flood soils of the study area which may be due to the fixation of phosphorus by increased iron content in the soils (Beegum, 2016).

Available boron content was sufficient for 40.06 per cent of soils in the pre-flood condition but severe depletion in boron content was reported in the study area in post flood condition (93.33 per cent). Depletion in boron content in study area might be due to the leaching of available boron due to high intensity rainfall (Mengel *et al.,* 2001).

Available potassium content was high for 76 per cent of soils in the present study which is in contradiction to the pre-flood condition where 57.59 per cent soils reported medium status in available potassium and only 20.41 per cent of soil reported high available potassium content. The increase in potassium content in the study area might be attributed by high organic matter content and saline water intrusion (Nath, 2016). 78 per cent of soils were deficient in available calcium content in the pre-flood soils but the status of calcium content in the soils have increased after flood and the entire samples reported to be sufficient in calcium content. The same trend was followed for available magnesium content in the soil. Magnesium content was deficient in 99.88 per cent of soils in the pre-flood scenario but an increase in magnesium content was reported after the flood in which 98.66 per cent of soils showed sufficiency with respect to magnesium status. Increase in calcium and magnesium content might be due to the effect of sediments deposited by the flood water. High input of liming materials might have ensured sufficient level of calcium and magnesium in the study area.

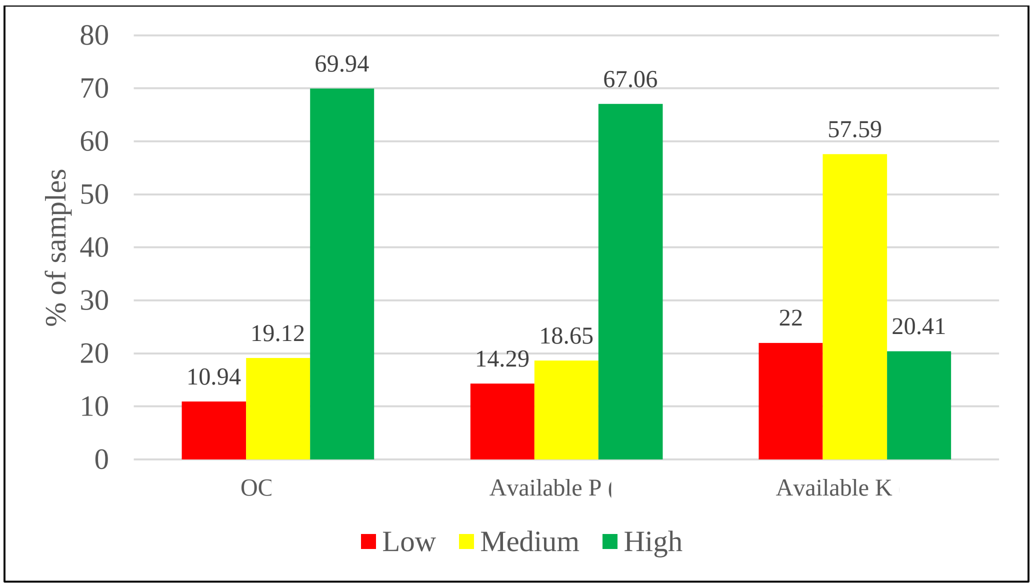

Fig. 40 Organic carbon, available phosphorus and potassium status in pre-flood soils of AEU 4 in Alappuzha district

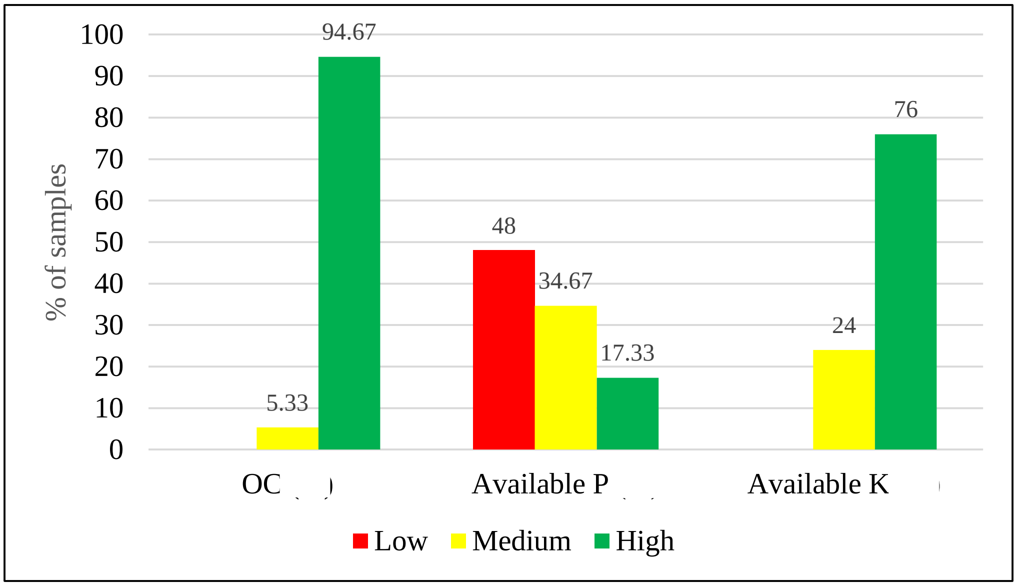

Fig. 41 Organic carbon, available phosphorus and potassium status in post flood soils of AEU 4 in Alappuzha district

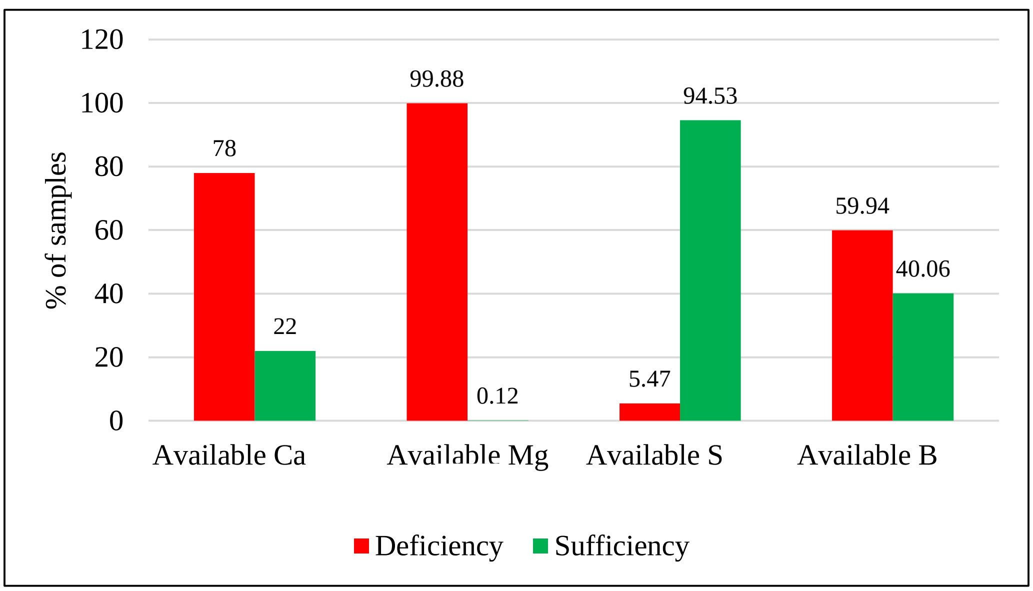

Fig. 42 Available calcium, magnesium, sulphur and boron status in pre-flood soils of AEU 4 in Alappuzha district

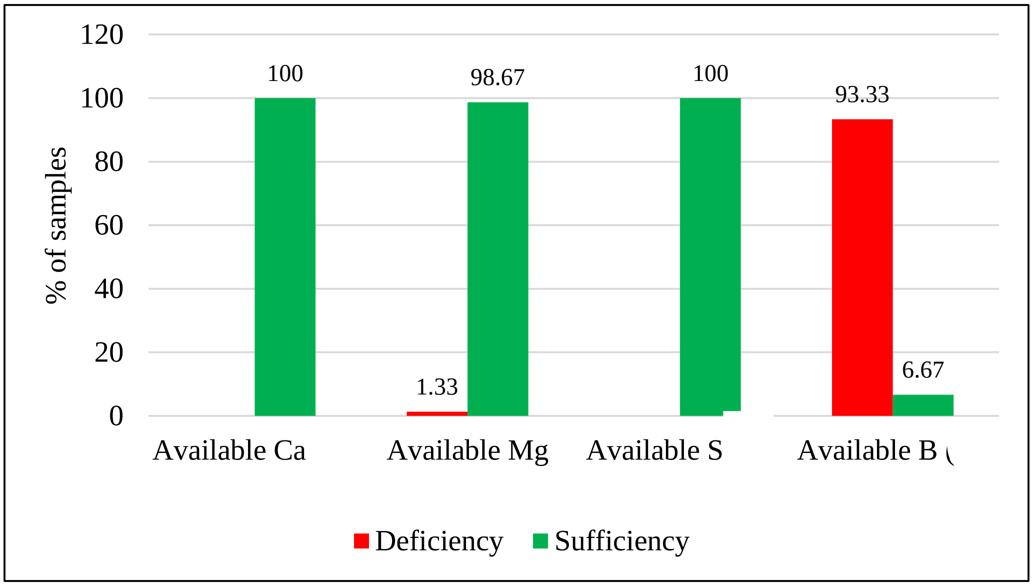

Fig. 43 Available calcium, magnesium and sulphur content in post flood soils of AEU 4 in Alappuzha district

5.6 RECOMMENDED CROP MANAGEMENT PRACTICES IN THE POST FLOOD SCENARIO

The results of soil quality analysis conducted in the flood affected areas of the AEU 4 of Alappuzha district can be considered as a base for the further modifications and recommendations in the crop management practices to be followed in the AEU 4.

An increase in soil acidity was reported in the present study which demands for the adequate and timely application of the liming materials for acidity amelioration. Even though organic carbon content in the study area showed tremendous increase, available nitrogen content in most of the soils were in medium status. In order to meet the crop requirements, application of nitrogenous fertilizers preferably Urea has to be undertaken in split doses. This will reduce the leaching loss of nitrogen in soil. Available phosphorus content in most of the soils were low except Ambalappuzha South and Kainakary. The low availability of the P status has to be taken into consideration to modify the recommended dose of further P fertilizer applications to the soil. Available boron content showed deficiency in 93.33 per cent of post flood soils of AEU 4. Foliar application of borax @ 0.5% or solubor @ 0.2 % can be recommended to correct the boron deficiency. Need based application of micronutrients has to be undertaken in the study area to maintain the soil health. Majority of soils studied fell into good soil quality status after the flood. Site specific and crop specific management practices have to be adopted in the study area to maintain soil quality and to get steady profit from crop cultivation.

SUMMARY

6. SUMMARY

The present study "Assessment of soil quality in the post-flood scenario of AEU 4 in Alappuzha District of Kerala and generation of GIS maps" was carried out during 2018-2020 in the Department of Soil Science and Agricultural Chemistry. The study was envisaged to evaluate the soil quality of post flood soils of AEU 4 in Alappuzha district. 75 geo-referenced surface soil samples were collected from 17 flood affected panchayats of AEU 4 in Alappuzha district and characterized for physical, chemical and biological attributes.

The salient findings of the first phase involving the Survey, collection and characterization are furnished below.

- A survey was conducted in the flood affected areas of AEU 4 of Alappuzha district with the help of a pre framed questionnaire to assess the nutrient management and cropping history of the study area.
- It was noticed that Kuttanad (AEU 4) was one of the worsely affected areas in Kerala during the floods in 2018 and the occurrence of flood in Kuttanad was three times during the period from July to August of 2018.
- Major parts of the area were submerged during the entire phase of flood and various roads and bunds were broken in many parts of Kuttanad.
- About 86.67 per cent of the farmers had a holding size less than 1 ha and belonged to the category of marginal farmers and the rest were small farmers (13.33).
- An estimated loss of ten thousand to twenty five thousand rupees per acre was incurred for many paddy farmers. Majority of the farmers follow conventional method of farming practices in the paddy fields.
- Rice is grown collectively in padashekharams and to maximize the yield farmers resort to the use of chemical fertilizers. Dolomite and lime were commonly used as liming material to mitigate acidity problems. Fertilizers such as Urea, Factomfos and Muriate of Potash were used predominantly as nutrient sources for paddy cultivation.

- With respect to physical characterization of the soil samples collected, 78.67 per cent were low in bulk density with values less than 1.2 Mg m^{-3}. Pandanad recorded the highest value for bulk density (1.43 Mg m^{-3}). The particle density of the soils follows the same trend as that of bulk density with 81.34 per cent soils having a particle density less than 2.2 Mg m^{-3}. The lowest mean value for particle density was recorded in Kavalam (1.67 Mg m^{-3}).
- Porosity of 92 per cent of samples were greater than 30 per cent and the highest value was recorded from Neelamperoor.
- With respect to soil texture, it is observed that the prominent soil texture exhibited by the soils was sandy clay loam which was exhibited by 41.34 per cent of soils followed by clay loam (21.34 per cent).
- Water holding capacity of soils were comparatively high and about 96 per cent of soils had water holding capacity greater than 30 per cent. Moisture content in 72 per cent of soils were greater than 25 per cent and the highest value was recorded from Veliyanad.
- Purakkad recorded the highest value for per cent of water stable aggregates and mean weight diameter.
- In the case of chemical characterization, a significant variation was noticed among the 17 panchayats. Most of the soils in AEU 4 of Alappuzha district belonged to extremely acid category with lowest value recorded in Neelamperoor where the available sulphur content recorded the highest value. EC of 98.67 per cent of samples were less than 1 dS m^{-1}.
- Even though organic carbon content of 94.67 per cent of samples were high, nitrogen content in the study were ranged from low to high with most of the samples fall under medium fertility status (69.33 per cent). Phosphorus content of most of the soils belonged to low (48 per cent) category which may be attributed by the fixation of phosphorus by iron and aluminium oxides and the highest value was reported from Ambalappuzha South. Potassium content in the post flood soils of

Kuttanad were medium to high in fertility with highest value recorded from Purakkad.

- In the case of secondary nutrients, More than 90 per cent of soils were sufficient in available calcium and magnesium with Kainakary recorded the highest value for both calcium and magnesium. Sulphur was sufficient in all the samples.
- 93.33 per cent of soils were deficient in available boron which may be due to leaching of soluble boron present in the soil.
- In the case of biological characterization, the activity of the enzyme acid phosphatase showed an inverse relationship with available phosphorus .The highest value was recorded from Veliyanad and the lowest value was recorded from Ambalappuzha South where available phosphorus recorded the highest value.

The salient findings of second phase involving Setting up of a Minimum Data Set (MDS) for assessment of soil quality (SQ) and the third phase involving the formulation of Soil Quality Index (SQI) are summarized as follows:

- Soil quality evaluation was carried out by creating minimum data set (MDS) using principal component analysis (PCA). Out of 20 attributes, 11 were selected for MDS and soil quality index for the study area was worked out.
- The eleven attributes retained in the MDS includes sand content, soil porosity, per cent of water stable aggregates, pH, EC, organic carbon content, available K, Ca, Mg and acid phosphatase.
- Soil quality evaluation of the study area was computed by assigning appropriate scores and weights to the indicators selected for MDS. SQI and RSQI were computed and it was observed 81.33 per cent of soils were of in high range for soil quality
- Of the 17 flood affected panchayats, Veliyanad panchayat recorded the highest value for Soil Quality Index where organic content, acid phosphatase activity, available Ca and Mg present in high status.

- Nutrient Index for OC and available K recorded high status in all panchayats while Kavalam and Kainakary the highest value for nutrient index for nitrogen and phosphorus respectively.
- LQI of all panchayats were belonged to low status except Veliyanad and Purakkad which fall under medium category. The highest LQI was recorded for Purakkad panchayat where organic carbon content recorded second highest value.
- Correlation study results of organic carbon content with soil physical parameters revealed that organic carbon content in the soil had negative correlation with bulk density, particle density, porosity, and sand content whereas correlation analysis of chemical attributes with biological parameter showed that soil pH was negatively correlated with available sulphur content. Acid phosphatase activity showed a negative correlation with available phosphorus content

The salient findings of fourth phase involving the generation of maps using Geographical Information Systems (GIS) of are summerized as follows:

- Thematic maps were prepared for soil texture, pH, organic carbon content, available N, P, K. Ca, Mg, S, B , RSQI, nutrient index (OC, available N, P,K) and LQI

The result obtained from the present study was compared with the pre flood data of Kerala State Planning Board (KSPB) 2013. The salient findings of the comparison of pre flood data with that of the post flood data are furnished as follows:

- Soil acidity of the post flood soils got increased with 78.67 per cent of soil samples belonged to extremely acidic category whereas only 21 per cent of samples belonged to extremely acidic category in pre flood soils.
- Organic carbon content, available potassium, calcium and exhibited an increase in their status in the post flood soils whereas available phosphorus and boron showed a declining trend

CONCLUSION

The present study revealed that even though flood incurred agricultural loss in Kuttanad, it had a positive impact on soil quality which was revealed by the bumper harvest in the next puncha season. Soil nutrient status for nitrogen, potassium, calcium, magnesium and sulphur got increased in the study area whereas significant drop was observed for soil acidity, available phosphorus and boron content. Based on LQI, Purakkad and Veliyanad panchayths were regarded as the best suitable for agricultural use among the 17 panchayths selected for present study and Veliyanad recorded the highest RSQI value depicting the best quality soil.

FUTURE LINE OF WORK

- The integration of micronutrients and biofertilizers in the rice cultivation practices and their impact on growth and yield of rice can be further investigated
- Investigations on the site specific management that has to be adopted in Kuttanad (AEU 4 of Alappuzha district) to maintain high yield as well as scopes for INM can be initiated in future.

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ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 4 IN ALAPPUZHA DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

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Abstract of the thesis

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ABSTRACT

The present study was carried out during 2018-20 in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani. The study was envisaged to assess the soil quality of post flood soils of AEU 4 in Alappuzha district and to work out soil quality index (SQI). A preliminary survey was conducted using a pre-designed questionnaire to assess the effect of flood and cropping history of the locality. Rice is the major crop cultivated in the study area and majority of the farmers follow conventional method of farming practices in the paddy fields. On the basis of survey conducted in the post flood areas, 75 geo referenced surface soil samples were collected from 17 flood affected panchayats of AEU 4 in Alappuzha district. The soil samples were analysed for physical (bulk density, particle density, porosity, moisture content, water holding capacity, aggregate stability), chemical (pH, EC, organic carbon, available N, P, K, Ca, Mg, S and B) and biological (acid phosphatase) attributes.

From the study, it was observed that bulk density of 78.67 per cent of samples were lower than 1.20 Mg m^{-3} while that of particle density of 81.34 per cent of samples were less than 2.2 Mg m^{-3}. The lowest value for particle density was observed in Kavalam (1.67 Mg m^{-3}). Neelamperoor recorded the highest value for porosity (64.7 per cent), clay content (42.3 per cent) and water holding capacity (57.1 per cent) and the lowest value for sand per centage (22.7 per cent) and bulk density (0.66 Mg m^{-3}). The predominant textural class observed in the soil samples of the study area belonged to sandy clay loam category.

From the perusal of the data, it was observed that 78.67 per cent soils were extremely acidic and 98.67 per cent of samples had EC less than 1 dS m^{-1}. 94.67 per cent of soils were high in organic carbon content and the highest value was recorded from Neelamperoor (5.39 per cent). With regard to major nutrients, available nitrogen content was medium (69.34 per cent), available phosphorus content was low (48 per cent) and Available potassium was high (76 per cent) for most of the samples. Highest and lowest values for available Ca and Mg were recorded from Kainakary and Pandanad respectively. In the case of boron, 93.33 per cent of samples were deficient in boron. Acid phosphatase

activity was found to be the highest in Veliyanad and while the lowest value was noticed in Ambalappuzha South panchayat.

Soil quality evaluation was done by scoring of indicators in minimum data set and integration of the indicator scores into SQI. Statistical tool, principal component analysis (PCA) was used for the selection of MDS and the indicators selected include porosity, WSA, sand content, pH, EC, organic carbon, available K, Ca, Mg and B and acid phosphatase. The highest SQI was reported in Veliyanad while the lowest value was recorded from Puliyur.

Land Quality Index (LQI) and Nutrient index (NI) were computed for the study area and LQI was the highest for Purakkad (8.39) followed by Veliyanad (6.47). Kavalam reported highest value for nutrient index of nitrogen whereas Kainakary reported the highest nutrient index value for phosphorus. Correlation study of the analysed parameters was carried out and thematic soil maps were generated for the analysed parameters using ArcGIS software.

Comparative evaluation of pre flood data from State Planning Board (2013) with that of the post flood data generated in the present study revealed that soil acidity has increased after flood. The flood has a positive impact on organic carbon content, available K, Ca and Mg by increasing the status while the status of available P and B got decreased.

Appendices

Appendix I.

Questionnaire used for survey in the study area

Name of the panchayat :

Name of the farmer :

Address :

Size of holding :

Suevey No. :

Geocoordinates of the sample :

Crops cultivated :

Nutrient management practices :

Depth of sand/silt/clay deposition :

Appendix II.

Area and crop management of sampled locations

Panchayat/ Municipality	Sample no.	Size of holding	Crops	Nutrient management practice
Alappuzha Municipality	1	0.50 ha	Rice	Conventional
	2	0.60 ha	Rice	Conventional
	3	0.91 ha	Rice	Conventional
	4	0.50 ha	Rice	Conventional
	5	1.21 ha	Rice	Conventional
	6	1.01 ha	Rice	Conventional
Kainakary	7	0.40 ha	Rice	Conventional
	8	1.21 ha	Rice	INM
	9	0.78 ha	Rice	Conventional
	10	0.61 ha	Rice	Conventional
	11	0.81 ha	Rice	INM
	12	0.50 ha	Rice	Conventional
	13	0.71 ha	Rice	Conventional
	14	0.95 ha	Rice	Conventional
	15	0.61 ha	Rice	INM
Champakulam	16	0.50 ha	Rice	Conventional
	17	0.60 ha	Rice	Conventional
	18	1.41 ha	Rice	Conventional
	19	0.71 ha	Rice	INM
	20	0.95 ha	Rice	Conventional
	21	0.81 ha	Rice	Conventional
	22	0.71 ha	Rice	Conventional

Panchayat/ Municipality	Sample no.	Size of holding	Crops	Nutrient management practice
Nedumudi	23	1.61 ha	Rice	Conventional
	24	0.60 ha	Rice	Conventional
	25	0.71 ha	Rice	Conventional
Pulinkunnu	26	1.01 ha	Rice	Conventional
	27	0.40 ha	Rice	Conventional
	28	1.61 ha	Rice	Conventional
	29	1.20 ha	Rice	Conventional
	30	1.21 ha	Rice	INM
	31	0.81 ha	Rice	Conventional
	32	0.72 ha	Rice	Conventional
	33	0.90 ha	Rice	Conventional
Veliyanad	34	0.81 ha	Rice	Conventional
	35	0.75 ha	Rice	Conventional
	36	0.50 ha	Rice	INM
Neelamperoor	37	0.95 ha	Rice	Conventional
	38	0.41 ha	Rice	Conventional
	39	0.95 ha	Rice	INM
	40	0.61 ha	Rice	Conventional
Kavalam	41	0.81 ha	Rice	Conventional
	42	0.61 ha	Rice	Conventional
	43	0.71 ha	Rice	Conventional
	44	0.88 ha	Rice	INM
Muttar	45	0.40 ha	Rice	Conventional
	46	0.75 ha	Rice	Conventional
Ramankary	47	0.61 ha	Rice	INM
	48	0.40 ha	Rice	Conventional

Panchayat/ Municipality	Sample no.	Size of holding	Crops	Nutrient management practice
Ramankary	49	1.82 ha	Rice	Conventional
	50	0.60 ha	Rice	Conventional
	51	0.71 ha	Rice	INM
	52	0.95 ha	Rice	Conventional
Ambalappuzha South	53	0.81 ha	Rice	Conventional
	54	0.50 ha	Rice	INM
	55	0.71 ha	Rice	Conventional
	56	0.85 ha	Rice	Conventional
Purakkad	57	0.95 ha	Rice	INM
	58	0.82 ha	Rice	Conventional
	59	0.71 ha	Rice	Conventional
Thakazhi	60	0.78 ha	Rice	Conventional
	61	0.50 ha	Rice	INM
	62	0.48 ha	Rice	Conventional
Edathua	63	0.85 ha	Rice	INM
	64	0.91 ha	Rice	Conventional
	65	0.95 ha	Rice	Conventional
Edathua	66	0.95 ha	Rice	Conventional
Thalavadi	67	0.81 ha	Rice	Conventional
	68	0.85 ha	Rice	INM
	69	0.71 ha	Rice	Conventional
Pandanad	70	0.41 ha	Rice	Conventional
	71	0.81 ha	Rice	Conventional
	72	0.61 ha	Rice	Conventional
	73	0.71 ha	Rice	Conventional
Puliyur	74	0.75ha	Rice	Conventional
	75	0.41 ha	Rice	Conventional

Appendix III.

Analysis results of individual samples

1. Analysis results of soil physical properties (individual samples)

Sample No.	Texture	WSA	MWD	Bulk density	Particle density	Porosity	Moisture Content	WHC
Alappuzha Municipality								
1	Sandy loam	77.1	1.48	1.58	2.27	30.4	18.8	32.7
2	Sandy loam	75.1	1.55	1.58	2.27	30.4	18.8	32.7
3	Sandy clay loam	76.2	1.32	1.33	1.99	33.0	31.1	38.4
4	Sandy loam	74.5	1.47	1.33	1.99	33.0	31.1	38.4
5	Sandy loam	76.4	1.40	1.13	2.66	57.7	14.	40.2
6	Sandy loam	83.2	1.60	1.13	2.66	57.7	14.	40.2
Kainakary								
7	Sandy loam	47.1	0.88	0.91	1.89	51.6	43.6	65.2
8	Sandy loam	55.7	1.30	0.91	1.89	51.6	43.6	65.2
9	Sandy clay loam	78.0	2.10	1.25	1.66	24.2	23.6	55.1
10	Sandy loam	69.5	1.31	1.02	2.20	53.9	35.7	47.4
11	Sandy loam	71.5	1.65	1.02	2.20	53.8	35.7	47.4
12	Sandy clay loam	67.1	1.55	1.02	2.03	50.0	41.0	48.8
13	Sandy clay loam	90.3	2.22	1.02	2.03	50.0	41.0	48.8
14	Clay loam	62.9	1.64	0.89	1.88	52.6	50.8	65.6
15	Sandy loam	77.8	1.57	1.04	1.83	43.3	39.2	41.5
Champakulam								
16	Loam	59.9	1.69	1.18	1.82	34.7	40.6	53.4
17	Sandy clay loam	74.3	1.59	1.14	1.97	42.0	41.1	47.4
18	Sandy clay loam	64.1	1.38	1.14	1.97	42.0	41.1	47.4
19	Sandy clay loam	69.4	1.31	0.99	2.28	56.6	45.4	52.3
20	Sandy clay loam	76.0	1.61	0.99	2.28	56.6	45.4	52.3

Sample No.	Texture	WSA	MWD	Bulk density	Particle density	Porosity	Moisture Content	WHC
21	Silty clay loam	53.1	1.16	1.01	1.74	42.3	37.7	46.8
22	Sandy clay loam	72.9	1.34	0.99	2.76	64.1	40.0	46.8
Nedumudi								
23	Sandy clay loam	67.0	1.37	1.12	1.99	43.5	46.5	51.3
24	Sandy clay loam	83.0	1.97	1.12	1.99	43.5	46.5	51.3
25	Clay loam	47.1	0.95	1.07	1.98	46.1	23.7	45.9
Pulinkunnu								
26	Sandy clay loam	73.9	1.68	0.91	1.89	51.9	39.2	42.8
27	Sandy clay loam	52.9	1.10	0.91	1.89	51.9	39.2	42.8
28	Clay loam	65.1	1.72	0.88	1.73	49.2	34.6	47.1
29	Sandy clay loam	57.0	1.45	1.21	2.01	39.8	38.5	43.1
30	Sandy clay loam	81.2	1.72	1.17	1.94	39.9	38.1	47.0
31	Sandy clay loam	92.2	1.98	1.17	1.94	39.9	38.1	47.0
32	Clay	69.7	2.23	0.74	1.69	56.1	43.3	53.8
33	Clay	68.3	1.60	0.74	1.69	56.1	43.3	53.8
Veliyanad								
34	Clay loam	83.5	2.44	0.79	1.80	56.4	49.7	55.3
35	Clay loam	73.7	2.21	0.79	1.80	56.4	49.7	55.3
36	Loam	69.8	1.82	1.36	2.36	42.2	54.7	57.2
Neelamperoor								
37	Silty clay	75.7	1.77	0.79	1.96	60.0	39.8	56.3
38	Clay loam	70.6	1.79	0.79	1.96	60.0	39.8	56.3
39	Clay loam	75.5	2.05	0.54	1.78	69.6	47.8	57.9
40	Clay loam	74.6	2.19	0.54	1.78	69.6	47.8	57.9
Kavalam								
41	Clay loam	64.6	1.83	1.01	1.75	42.4	37.1	44.8
42	Sandy clay loam	62.9	1.31	0.97	1.51	35.7	41.8	42.6

Sample No.	Texture	WSA	MWD	Bulk density	Particle density	Porosity	Moisture Content	WHC
43	Sandy clay loam	72.9	1.78	0.97	1.51	35.7	41.8	42.6
44	Clay	73.3	2.15	0.83	1.75	52.5	46.8	50.5
Muttar								
45	Clay loam	55.2	1.04	0.78	1.78	56.2	40.0	45.2
46	Clay loam	59.2	1.30	0.86	1.89	54.3	37.5	44.3
Ramankary								
47	Sandy clay loam	69.5	1.47	0.50	1.89	73.4	49.8	61.4
48	Sandy clay loam	59.0	1.08	0.50	1.89	73.4	49.8	61.4
49	Sandy clay loam	66.8	1.27	0.98	1.89	48.3	48.3	58.6
50	Sandy clay loam	75.7	1.47	0.98	1.89	48.3	48.3	58.6
51	Sandy clay loam	63.2	1.82	1.12	1.79	37.3	32.9	38.8
52	Sandy clay loam	63.2	1.64	1.12	1.79	37.3	32.9	38.8
Ambalappuzha South								
53	Sandy clay loam	69.4	1.38	1.47	2.01	26.7	14.4	33.9
54	Sandy clay loam	61.0	1.16	1.47	2.01	26.7	14.4	33.9
55	Sandy loam	71.6	1.41	1.22	2.37	48.7	20.0	48.6
56	Sandy loam	78.8	1.68	0.99	1.48	32.9	17.0	28.1
Purakkad								
57	Clay	86.7	2.33	1.03	1.83	44.1	22.0	43.5
58	Clay	77.5	2.23	1.03	1.83	44.1	22.0	43.5
59	Sandy loam	79.3	1.88	1.12	1.97	42.9	27.1	46.9
Thakazhi								
60	Loam	65.9	1.06	1.09	2.00	45.5	44.6	48.8
61	Clay loam	54.0	1.02	1.02	2.97	65.7	43.0	59.0
62	Loam	70.5	1.62	0.85	1.71	50.3	38.2	67.7
Edathua								
63	Clay loam	53.8	1.50	0.92	1.81	49.0	41.2	57.3

Sample No.	Texture	WSA	MWD	Bulk density	Particle density	Porosity	Moisture Content	WHC
64	Clay loam	55.0	1.45	0.92	1.81	49.0	41.2	57.3
65	Sandy clay	74.3	1.68	0.52	2.16	75.7	52.9	63.5
66	Loam	67.2	1.64	0.97	1.99	51.3	23.1	31.8
Thalavadi								
67	Clay loam	72.0	1.44	0.88	2.21	60.0	20.8	39.0
68	Clay loam	69.1	1.25	0.88	2.21	60.0	20.8	39.0
69	Loam	74.6	1.65	0.96	1.88	48.8	20.1	64.1
Pandanad								
70	Sandy clay loam	77.2	1.75	1.45	1.98	26.7	10.2	32.0
71	Sandy clay loam	65.4	1.10	1.45	1.98	26.7	10.2	32.0
72	Sandy clay loam	60.0	1.03	1.43	2.05	30.1	17.8	34.1
73	Clay	55.9	0.99	1.40	2.01	30.1	21.2	29.8
Puliyur								
74	Sandy clay loam	80.2	1.82	1.56	2.20	28.7	13.7	25.8
75	Sandy clay loam	68.2	1.68	1.28	2.08	38.4	35.8	43.9

2. Analysis results of chemical and biological properties (individual samples) in post flood soils of AEU 4 in Alappuzha district

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
Alappuzha Municipality											
1	4.48	0.80	1.99	226	22.9	526	640	516	605	0.25	29.2
2	3.95	0.56	2.70	238	10.6	594	540	396	746	0.15	11.0
3	4.40	0.81	1.50	213	34.9	549	1360	624	791	0.26	27.6
4	4.28	0.72	2.16	251	15.9	750	1440	636	880	0.46	33.3
5	4.16	0.64	0.84	138	36.1	213	540	360	601	0.14	18.8
6	4.18	0.67	2.10	238	17.1	582	960	384	633	0.18	24.4
Kainakary											
7	3.58	0.44	1.88	426	35.9	370	840	600	1205	0.15	22.5
8	4.47	0.54	2.64	314	19.5	470	680	480	477	0.30	27.4
9	4.81	0.53	2.64	326	33.6	773	1200	600	255	0.14	29.9
10	4.40	0.71	1.82	226	10.4	459	800	600	541	0.13	32.5
11	4.18	0.63	2.31	339	13.6	672	1120	840	933	0.12	24.4
12	4.39	0.48	2.67	451	28.0	784	380	264	637	0.26	17.9
13	4.60	0.67	3.03	326	18.3	986	1020	900	177	0.34	28.3

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
14	4.06	0.78	2.81	401	16.9	616	1520	948	1001	0.22	51.8
15	4.62	0.81	2.55	389	24.8	829	740	480	422	0.44	43.2
Champakulam											
16	3.96	0.59	2.84	414	24.3	448	780	468	955	0.41	30.1
17	5.21	0.67	2.39	414	13.9	571	580	492	335	0.12	21.2
18	4.10	0.40	1.89	376	25.7	750	720	540	389	0.57	81.7
19	3.95	0.66	1.82	276	7.18	258	480	360	846	0.22	23.5
20	4.10	0.57	2.49	364	11.3	470	980	420	639	0.00	41.2
21	4.09	0.81	4.26	564	7.41	672	800	600	885	0.22	69.8
22	4.88	0.90	1.29	163	28.9	538	500	420	234	0.58	26.0
Nedumudi											
23	4.17	0.63	2.21	376	10.2	470	640	480	869	0.22	29.8
24	4.20	0.44	2.46	364	6.25	515	940	480	676	0.06	49.4
25	4.37	0.72	1.95	276	9.03	358	700	420	542	0.28	35.7
Pulinkunnu											
26	4.24	0.45	2.79	339	12.3	246	640	336	591	0.30	52.2

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
27	4.40	0.39	2.37	452	20.4	213	640	312	772	0.01	17.3
28	4.14	0.88	3.60	376	8.34	650	660	312	599	0.13	96.1
29	4.21	0.45	2.06	288	7.64	829	460	360	501	0.01	43.8
30	3.94	0.75	2.84	452	30.6	426	820	300	1024	0.08	23.3
31	4.20	0.50	3.48	364	28.9	291	680	552	472	0.12	25.1
32	3.93	0.67	4.20	489	11.3	202	580	372	1109	0.04	13.2
33	3.92	0.64	3.63	464	12.3	123	580	408	495	0.00	29.2
Veliyanad											
34	4.41	0.43	4.83	652	8.57	347	580	276	373	0.06	86.5
35	3.78	0.53	4.08	564	7.87	202	480	252	469	0.01	52.7
36	4.14	0.68	4.35	590	6.25	224	1300	216	852	0.18	38.2
Neelamperoor											
37	3.56	0.74	5.55	552	6.48	392	560	372	1147	0.24	18.4
38	3.50	0.56	5.37	564	7.87	202	820	528	969	0.01	40.0
39	3.48	0.58	4.98	539	8.10	381	720	360	1217	0.03	21.5
40	3.60	0.47	5.67	527	6.71	157	1120	828	1245	0.50	25.5

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
Kavalam											
41	4.11	0.67	4.26	577	11.1	974	660	408	996	0.19	21.2
42	3.85	0.58	2.81	489	9.49	403	580	276	843	0.34	22.6
43	3.54	0.56	3.63	602	8.57	123	880	672	991	0.25	38.2
44	4.01	0.59	5.46	414	7.41	661	800	600	994	0.57	20.9
Muttar											
45	4.48	0.63	2.78	477	4.86	269	760	264	271	0.10	47.4
46	4.17	0.71	3.69	364	6.71	336	720	528	201	0.06	59.4
Ramankary											
47	4.16	0.75	2.85	389	6.48	370	600	360	976	0.30	45.6
48	3.50	0.63	2.34	376	8.34	470	720	240	1081	0.20	23.2
49	4.23	0.58	2.30	389	5.56	157	980	252	500	0.18	19.1
50	4.10	0.63	2.34	414	5.09	437	880	300	1126	0.22	33.3
51	4.33	0.81	4.47	464	10.6	370	1080	600	294	0.12	62.0
52	3.95	0.85	4.08	364	9.96	482	640	696	327	0.21	49.5

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
Ambalappuzha South											
53	3.65	0.77	2.16	489	18.9	246	500	480	1084	0.02	11.5
54	3.25	0.64	2.10	401	13.9	134	680	360	1008	0.07	16.2
55	3.69	0.45	1.32	251	31.5	750	380	110	523	0.31	13.6
56	3.60	0.62	2.82	314	32.4	885	560	444	437	0.33	14.5
Purakkad											
57	3.68	0.81	5.58	276	9.96	493	900	492	781	0.52	15.7
58	3.72	0.84	5.37	401	9.26	582	920	504	1022	0.25	15.5
59	3.72	0.98	4.95	427	9.49	941	340	144	795	0.36	14.5
Thakazhi											
60	3.75	0.87	3.30	351	12.0	437	700	384	935	0.23	21.5
61	4.17	0.77	2.64	276	9.49	784	540	300	356	0.13	23.5
62	3.62	0.56	4.74	539	6.95	750	800	613	1242	0.32	20.4
Edathua											
63	3.80	0.89	4.29	464	4.63	302	660	374	949	0.18	44.5
64	3.14	0.76	4.08	401	5.56	336	580	482	902	0.13	55.6

Sample No.	pH	EC (dS m^{-1})	Organic carbon (%)	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg of p-nitrophenol released g^{-1} soil h^{-1})
65	4.40	0.69	4.14	414	10.9	493	600	374	282	0.17	38.4
66	4.66	0.60	3.96	477	8.57	650	680	372	273	0.09	54.9
Thalavadi											
67	4.81	0.80	2.07	489	11.1	582	600	253	158	0.30	40.7
68	4.30	1.00	1.44	313	18.3	493	800	374	240	0.29	17.1
69	4.56	0.50	3.54	414	12.5	235	800	480	273	0.34	49.8
Pandanad											
70	3.94	0.95	3.63	389	6.95	414	440	252	905	0.08	45.8
71	3.35	0.59	2.91	339	7.99	358	420	211	677	0.02	54.2
72	5.12	0.44	1.92	201	9.03	370	500	190	22	0.03	21.9
73	4.87	0.30	1.92	314	8.96	190	480	252	24	0.10	54.3
Puliyur											
74	4.86	0.49	1.56	201	9.73	224	640	289	125	0.21	17.9
75	4.71	0.23	2.21	175	15.9	280	320	180	37.5	0.15	28.3

3. Land quality index (LQI), Soil quality index (SQI) and relative soil quality index (RSQI) of the post flood soils (individual samples) in AEU 4 of Alappuzha district.

Sample No.	LQI	SQI	RSQI
Alappuzha Municipality			
1	4.73	280	70.0
2	6.40	270	67.5
3	2.99	280	70.0
4	4.31	300	75.0
5	1.42	280	70.0
6	3.56	300	75.0
Kainakary			
7	2.56	280	70.0
8	3.60	290	72.5
9	4.95	270	67.5
10	2.78	300	75.0
11	3.53	300	75.0
12	4.09	280	70.0
13	4.64	310	77.5
14	3.74	300	75.0
15	3.98	310	77.5
Champakulam			
16	5.04	300	75.0
17	4.09	290	72.5
18	3.24	310	77.5
19	2.69	280	70.0
20	3.69	310	77.5

Sample No.	LQI	SQI	RSQI
21	6.43	300	75.0
22	1.92	310	77.5
Nedumudi			
23	3.72	280	70.0
24	4.15	300	75.0
25	3.12	280	70.0
Pulinkunnu			
26	3.81	310	77.5
27	3.23	280	70.0
28	4.74	300	75.0
29	3.73	280	70.0
30	4.97	280	70.0
31	6.10	290	72.5
32	4.67	260	65.0
33	4.03	260	65.0
Veliyanad			
34	5.69	320	80.0
35	4.81	300	75.0
36	8.90	290	72.5
Neelamperoor			
37	6.54	300	75.0
38	6.33	300	75.0
39	4.05	300	75.0
40	4.61	290	72.5
Kavalam			
41	6.45	280	70.0
42	4.08	280	70.0

Sample No.	LQI	SQI	RSQI
43	5.28	270	67.5
44	6.79	300	75.0
Muttar			
45	3.59	290	72.5
46	4.77	300	75.0
Ramankary			
47	2.15	310	77.5
48	1.77	290	72.5
49	3.37	260	65.0
50	3.43	300	75.0
51	7.52	290	72.5
52	6.86	280	70.0
Ambalappuzha South			
53	4.78	240	60.0
54	4.65	240	60.0
55	2.41	290	72.5
56	4.19	280	70.0
Purakkad			
57	8.59	290	72.5
58	8.26	280	70.0
59	8.33	290	72.5
Thalavadi			
60	5.40	290	72.5
61	4.04	280	70.0
62	6.03	320	80.0
63	5.93	290	72.5
64	5.64	290	72.5

Sample No.	LQI	SQI	RSQI
65	3.25	310	77.5
66	5.76	310	77.5
67	2.74	320	80.0
68	1.90	290	72.5
69	5.10	310	77.5
Pandanad			
70	7.90	280	70.0
71	6.33	270	67.5
72	4.13	270	67.5
73	4.05	250	62.5
Puliyur			
74	3.13	260	65.0
75	3.94	260	65.0

Appendix IV.

pH, organic carbon content and available nutrient status in the pre flood soils of AEU 4 in Alappuzha district (KSPB, 2013).

Soil parameter	Class	Per cent of soil samples
pH	Ultra acid	4.82
	Extremely acid	21.00
	Very strongly acid	24.76
	Strongly acid	25.47
	Moderately acid	17.76
	Slightly acid	4.76
	Neutral	1.43
Organic carbon	Low	10.94
	Medium	19.12
	High	69.94
Available phosphorus	Low	14.29
	Medium	18.65
	High	67.06
Available potassium	Low	22.00
	Medium	57.59
	High	20.41
Available calcium	Deficient	78.00
	Sufficient	22.00
Available magnesium	Deficient	99.88
	Sufficient	0.12
Available sulphur	Deficient	5.47
	Sufficient	94.53
Available boron	Deficient	59.94
	Sufficient	40.06