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

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(2018-11-064)

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COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM – 695 522

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by

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THESIS

Submitted in partial fulfilment of the requirements for the degree of

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VELLAYANI, THIRUVANANTHAPURAM – 695 522

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2020

DECLARATION

I hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 4 IN KOTTAYAM 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, associateship, fellowship or other similar title, of any other University or Society.

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<u>**CERTIFICATE**</u>

Certified that this thesis, entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 4 IN KOTTAYAM DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a record of research work done independently by **Ms. Anusha B.** (2018-11-064) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Introduction

1. INTRODUCTION

Kerala is one among the states which receives maximum amount of rainfall with one fifth of its area surrounded by water bodies. In 2018, Kerala witnessed a rainfall of 2346.6 mm from 01 June to 19 August, which was 42 % more than normal. This caused much havoc leading to a flooded situation in all the 14 districts of the state except Kasaragod. The scouring action of high intensity rainfall lead to severe soil erosion and deposition of sediments which affected the soil quality in terms of its physical, chemical and biological properties. Global change in climatic conditions may increase the frequency and severity of flood in South Asia (Turner and Annamalai, 2012) which can affect agriculture. The 2018 floods have adversely affected the livelihood, agricultural and other allied activities of the farmers.

The Kottayam district, which is located at the central part of the state is bordered in the west by Vembanad lake. The district is divided into three agro ecological units viz. AEU 4, AEU 9 and AEU 12. The wetland near the Vembanad lake is mainly cultivating paddy. Kuttanad, (AEU 4) known as the rice bowl of Kerala is comprised of Kari, Kayal and Karappadam soils. About one third of Kuttanad wetland consists of paddy fields called padasekharams, which have been retrieved form the marshes, the flood plains of rivers and the lake beds. Rice cultivation here is very peculiar due to the below sea level farming practice. This area experiences a number of soil fertility problems like acidity, salinity, nutrient deficiencies, Fe and Al toxicity etc. These soils are also characterized for having fair amounts of decaying organic matter.

Kottayam received 51 % more rainfall than normal from 01 June to 19 August. Due to this heavy rainfall event, the run off generated from Pamba, Manimala, Achenkovil and Meenachil rivers to the Vembanad lake generated a rise in water level in the lake and caused flooding in the nearby areas.

Flooded soil may experience “post flood syndrome” just like fallow syndrome, where the land is left unplanted. Flooding may erode the top soil (0-15 cm) which holds the plants, retains soil moisture, abundant in organic matter, microbial activity and earthworms. It may also cause various changes to the soil which was under submerged or waterlogged condition for an extended period of time in terms of their physical, chemical or biological characteristics and thus affect soil quality.

Doran and Parkin (1994) defined soil quality as the capacity of a soil to function within the ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health. For the assessment of soil quality, identification of suitable indicators that represent the system and their characterization is carried out.

The soil quality may deteriorate due to various reasons like loss of nutrients through leaching and runoff, depletion of organic matter, loss of microbial diversity, deposition of toxic chemicals, change in structural properties, crusting and compaction etc.

Despite of the adverse consequences of flooding on environment, particularly farming it may result in re-deposition of organic matter and minerals along with the water which make the soil fertile and more productive.

The problems encountered to the soil as a result of flooding should be addressed scientifically by analyzing the soil for various indicators and should interpret the data by employing modern methods of remote sensing and spatial mapping.

The present study was therefore undertaken to assess the impact of flooding on soil nutrient status as well as physical parameters in order to look into the possibility of modifying or changing the existing management practices. The study was undertaken with the following objectives:

1. The assessment of soil quality of post-flood soil of AEU 4 in Kottayam district of Kerala
2. To develop maps on soil characters & quality using GIS techniques.
3. To work out soil quality index (SQI)

Review of literature

2. REVIEW OF LITERATURE

2.1. KUTTANAD

Kuttanad is the rice bowl of Kerala and is a special agro-ecological unit which represents the waterlogged areas of Alappuzha, Kottayam and Pathanamthitta districts of Kerala. Major parts of this AEU are below, at or just above sea level. On the basis of morphological condition, it is further classified into kayal, kari and karappadam lands (Money, 1961; KAU, 2016).

Kurup and Aiyer (1973) studied the effect of submergence in acid sulphate soils of kerala and concluded that pH of kari and karappadom soils never exceeded a value of five and kayal soils a value of seven and pH value was recorded minimum in the samples collected in March – April. According to Thampatti (1997) a great degree of variation in morphological and physico-chemical properties of soil is observed in north kuttanad. Soils were reported to be dark brown to black in colour, sticky and plastic. Texture varied from sandy to clayey with sub angular blocky structure.

By considering the location, Kari soils are further divided to Vaikom kari and Purakkad kari. The major problem of kari soil is severe acidity and salinity problems (Nair and Money, 1972). This renders them problematic soils resulting in yield constraints (Devi *et al.,* 2017).

Saline sea water intrusion to the low lands are prevented by bunds and barrages and are mainly used for the cultivation of paddy, whereas the uplands are cultivated mainly for coconut, banana and vegetables.

Floods are considered to be a regular phenomenon in these area in monsoon due to the overflow of river waters. The area is also subjected to saline water intrusion from Arabian sea as the north-east monsoon receded (Thambatti and Padmakumar,1999).

The Kuttanad ecosystem is changing at an alarming rate due to various reasons including anthropogenic activities. Sreejith (2013) suggests that it is high time to act on it to maintain the ecological significance of the unique ecosystem.

2.1.1. Soil characteristics of Kuttanad soils

Morphological and physicochemical properties of the soils showed great degree of variation (Thampatti, 1997). Soils of Kuttanad is found to be severely acidic (Thampatti,1997; Beena,2005; Nath *et al.*, 2016). The pH ranges from 2.4 to 4.8 and EC values varied from 0.185 to 8.752 dS/m which was attributed to the saline water intrusion in summer (Nath *et al.*, 2016). Various acidity amelioration studies have been conducted in these areas (Devi *et al.*, 2017).

Potential acidity of the area was very high and more than 70 per cent of it was contributed by hydrolytic acidity and the rest by exchangeable acidity (Thampatti, 1997). Kuttanad soil have enormous amount of organic deposition.

The rice cultivation in this tract was always risky because of flood submergence during monsoons and saline water intrusion during summer. The studies on acid sulphate soils of Kuttanad suggest a higher potential acidity than exchangeable acidity (Indira and Thampatti, 2013).

All the nutrients except phosphorus was found to be adequate and organic carbon per cent was high. Dhanya (2017) found that soil organic carbon status and carbon pool indices were highest at Kallara series. She also indicated Kuttanad could act as a high potential carbon sink.

Thampatti (1997) confirmed that the area is undergoing severe pollution due to the accumulation of existing toxic factors and over use of agrochemicals.

2.2. FLOODING

2.2.1. Flooding in Kerala

According to IMD data, the state received 2346.6 mm of rainfall till the end of August,2018 against normal value of 1649.5 mm which was about 42 per cent more than normal. This led to much havoc leading to a flooded situation in all the districts except Kasaragod (ICAR-CTCRI, 2018).

Vishnu *et al.* (2019) on a satellite based study concluded that the flood water of most of the river basin receded by 21st August 2018 except the Kuttanad and Kole lands where the water recession showed a slow decline. The rise in water level was reported up to 5 m in Kuttanad in the month of August. He also commented that the damages caused to the bunds and embankments were mainly responsible for the filling up of the low lying paddy fields.

2.2.2. Effect of flooding on soil properties

Flooding results in considerable variations in pH and redox potential of soils. These variations affected the CEC of surface soil and thus the availability of major and micro nutrients. High Fe and Al toxicity of Kari soils demanded more lime applications. Physical properties of soil were also badly affected (KAU, 1994).

Flooding is known to further aggravate soil quality resulting in more degradation, crop loss and thus resulting in shortage of food. Within a short time after flooding, the free oxygen available will be taken up by the micro-organisms leading to anoxic condition.

Submergence causes depletion of oxygen or reduced condition in soil, which in turn may affect the chemistry of the soil-water system and consequently soil aggregation. Loss of soil aggregation impacts agriculture by decreasing soil quality and crop production. The disintegrated aggregates may clog the soil pores and further degrade the soil structure. The aggregate stability of cultivated soils was more affected by the reduced conditions than that of uncultivated soils (De-Campos *et al*., 2009).

Ponnamperuma (1984) summarized that flooding decreases the gaseous exchange of soil, depletes the oxygen content, swells the soil colloids, reduction of soil strength due to loss of cohesion and may also destructs the soil structure and hence the water movement. Sudden reduction in the gaseous exchange may cause the accumulation of CO_2, methane and hydrogen in soil.

Unger *et al*. (2009) reported a reduction in redox potential and soil oxygen status with increase in duration of flood both in flowing flood and stagnant flood condition. He also opinioned a reduction in NO_3-N and increase in NH_4-N in flooded soils.

A work conducted by Narteh and Sahrawat (1999) after a greenhouse experiment in West Africa concluded that the redox potential as the key electrochemical parameter with reduction in its values in flooded soils and affecting the crop production. Visser *et al.* (2003) also suggested oxygen depletion as the key parameter that affects the growth and cause injuring to plants in flooded condition.

Stagnation of water in the low lying areas not only restricts soil aeration but also impairs the root respiration by slowing down nutrient and water uptake, limits growth of the root system, stimulates toxic metabolism, disturbs hormone metabolism, and prevents the normal functioning of essential biological, chemical and physical processes associated with fertile and productive soils (Sil *et al.,* 2011).

The pH of an acid soil increased and alkaline soil decreased on flooding. Ponnamperuma (1972) reported that the pH values of most of the flooded mineral soils between 6.7 and 7.2. Specific conductance is believed to increase during first week and then declines to a stable value (Ponnamperuma, 1984).

Negative impact of flooding was reflected from the reduced concentration of potassium and other essential micronutrients such as Mn and Ni. There was an excess concentration of Cu and heavy metals such as Pb and Cd as reported by Akpoveta *et al.* (2014) in Asaba and Onitsha farmlands of Nigeria.

Unger *et al.* (2009) observed a decrease in microbial biomass, bacteria to fungi ratio, aerobic bacteria, gram positive and gram negative bacteria in stagnant flood condition in green house. Wilson *et al.* (2011) observed significant increase in soil respiration, enzymatic degradation and changes in microbial community structure.

Despite of the negative impacts of flooding, in many natural systems such as in fish farming, flood plays a key role in maintaining functioning of the ecosystem and biodiversity. As agricultural systems are concerned, flood may deposit organic and mineral deposits along with nutrients which make the soil fertile and productive (Akpoveta *et al.*, 2014).

Kalshetty *et al.* (2014) assessed the nutrient status in the soil and sediment samples due to flooding of Krishna river in Bagalkot district of Karnataka. Only Fe, Zn, and Cu were found to be slightly higher than the critical limits and among major nutrients, only nitrogen was found to be reduced as compared to non-flooded condition.

The study conducted by Njoku, (2017) found that the flood has improved almost all the physio-chemical properties of the soil which he concluded to be due to the deposition of minerals and organic residues to the soil which made the soil fertile and thereby more productive. The study also concluded that there were no short term pollution effects on the soil.

2.3. SOIL QUALITY

2.3.1. Concept and definition

A number of researchers have worked on soil quality and they tried to define the concept of soil quality in their own perspective. Larson and Pierce (1991) defined soil quality as the capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem. Parr *et al.* (1992) explained soil quality as the integration of various physical, chemical and biological growth factors that make a soil productive for a sustained production crops. He also broadened the concept to human and animal health, food safety and environment quality.

Later, Doran and Parkin (1994) defined soil quality as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.

Although soil quality can be simply defined as a soil's "fitness for use", in reality it is a complex concept and significantly more challenging in its assessment than air or water quality (Carter *et al*., 1997).

Hornick (1992) reported soil factors and climate as two among the major factors that affect nutritional quality and if these can be enhanced, it could improve nutritional quality and bioavailability of nutrients and this will be highly beneficial.

In some cases, due to faulty management activities, anthropogenic influence or any other climatic effects there may be a deterioration in the quality of soil who initially possessed good inherent properties.

According to Carter *et al.* (1997) soil quality basically possess two parts, (i) inherent soil quality (ii) dynamic soil quality. Inherent soil quality implies to the inherent capacity of soil to produce crops. They are constant over a period of time and evaluated by considering the extrinsic factors. Dynamic qualities are the ones which changes in shorter time period due to human as well as management factors (Karlen *et al.,* 2003).

There are two approaches in the quantification of soil quality, the descriptive approach where different attributes of soil quality are characterized and the indicative approach, where specific indicators or parameters are identified which asses the ability of attribute to function (Gregorich *et al.*,1994).

The concept of soil quality has been constantly evolved with the increase in knowledge and understanding of soils and their quality attributes (Karlen and Stott, 1994).

2.3.1. Assessment of soil quality and soil quality indicators

Arshad and Coen (1992) opinioned that soil properties, vegetation and hydrology can get affected by soil degradation. In this context periodic assessment of soil quality gained much importance.

The soils ability to sustain plant growth as well as maintaining its biological activity is a function of physical and chemical properties (Doran and Parkin, 1994). Soil quality is mainly considered to have physical, chemical and biological aspect which is found essential for assessing extend of degradation or amelioration and for planning suitable management for sustainability (Dexter, 2004).

Soil quality indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions (Arshad and Martin, 2002). The most sensitive attributes in a given management system is mostly suited as indicator

Generally, soil quality is assessed by a combination of various chemical, physical and biological indicators (Roming *et al.,* 1995; He *et al.*, 2003) but it is often difficult to separate various attributes in terms physical, chemical and biological aspect. Arshad and Coen (1992) considered organic matter as physical since they affect water retention, chemical as well as a biological attribute. Doran and Parkin (1994) considered mineralizable nitrogen as both physical and biological attribute.

Some measurable physical attributes like soil depth, WHC and water retention characteristics, aggregate stability, hydraulic conductivity, infiltration rate, bulk density are reported as indicators for assessing soil quality (Arshad and Coen, 1992).

Larson and Pierce (1991) proposed soil texture, structure, plant available water, and maximum rooting depth and soil strength as physical and nutrient availability, organic carbon, pH, and EC as chemical indicators of soil quality. Karlen and Stott (1994) considered that aggregates play a major role in determining the structure of soil

Chemical attributes like CEC, pH, base saturation, EC, ESP were considered as soil quality indicators by Arshad and Coen (1992). Soil tilth and resistance to water and wind erosion as physical indicators, properties such as pH, CEC, AEC, total and available plant nutrients, salinity and nutrient cycling as chemical and microbial activity as well as natural processes like respiration, mineralization and nitrification are identified as biological indicators by Karlen *et al.* (1992).

Doran *et al.* (1996) presented a list of properties affecting soil ecological functions and quality, for example soil bulk density, water infiltration and holding capacity, total organic C and N, electrical conductivity, pH, plant-available nutrients, and measures of microbial biomass and activity.

Biological indicators of soil quality are dynamic so, to develop an effective database for research they will require efficient monitoring and assessment (Parr *et al.*, 1992). The attributes that may be used as a soil quality indicator can be grouped mainly into four categories but they cannot be clearly designated to a particular category as an indicator can affect more than one soil function. These category includes,

(i) Physical attributes: They are mainly concerned with arrangement of solid particles of soil and pores (Norcliiff, 2002).

The nature and relative proportion of soil particles (primary and secondary) determine amount, morphology, continuity and interconnection of pores (Topp *et al.*,1970).

(ii) Chemical attributes: Here the list of potential soil attributes is very large and the final selection will depend upon the function under consideration. Attributes include, pH, salinity, aeration status, organic matter content, cation exchange capacity, status of plant nutrients, concentrations of potentially toxic elements and possibly the most important attribute, the capacity of the soil to buffer against change (Norcliff, 2002).

(iii) Biological attribute: They are the most dynamic and sensitive attribute to the changes in management. This included biomass carbon, organic carbon, soil respiration, enzymes, microbial community, nucleic acid analysis and potentially mineralizable nitrogen (Singer and Ewing, 2000).

(iv) Visual attributes: They are the observable changes that occur as a result of soil quality degradation. The major demerit of this attribute is that it appears late and the chances for restoration may be lost. This may include formation of rills as evidence of erosion, exposure of sub soil etc. (Norcliff, 2002).

The existing knowledge about soils based on quantitative knowledge of individual soil attributes must be replaced with the knowledge of soil quality based on integration of these properties. This can be established by generating soil quality index. Granatstein and Bezdicek (1992) states that an index generated must adaptable for regional or local condition.

2.4. MINIMUM DATA SET (MDS)

Larson and Pierce (1991) proposed that a minimum data set of different soil parameters have to be adopted for the assessment of health of world soils and in order to assess those factors, standard procedures need to be established.

A minimum set of data on soil indicators and relevant sampling strategies must be identified to develop meaningful soil quality assessment and monitoring program (Arshad and Martin, 2002).

Doran and Parkin (1996) opinioned that the indicators selected as MDS should describe the ecological processes and one should ensure that the measurements obtained are reflected in field condition.

The use of MDS will reduce the requirement for assessing a large number of indicators for assessing the quality of soil (Rezaei *et al*., 2006).

Based on ecological relevance various physical, chemical, biological attributes were enlisted which includes soil texture, infiltration, bulk density, WHC, soil organic matter, pH, EC, extractible N, P and K, microbial biomass C and N, soil respiration (Doran and Parkin, 1994; Larson and Pierce,1994) .

Assessment of soil quality using a minimum data set like texture, organic matter, pH, bulk density, and rooting depth was suggested by Gregorich *et al.* (1994). They considered that soil organic matter has particular significance in soil quality as it influences various other attributes including the attributes in MDS. They also suggested that the first step in assessing soil quality is the use of MDS consisting of different biochemical properties which is sensitive to management, inputs into the soil and pedoturbations.

de Lima *et al.* (2008) selected OM, Mn, Cu, MWD, Earthworm number as indicators to distinguish the soil management systems. Available water, bulk density, and micronutrients (Cu, Zn, Mn) as indicator to distinguish the soil textural classes in a rice based cropping system as MDS from a total of 29 different physical chemical and biological attributes.

Li *et al.* (2019) retained only those parameters which showed significant correlation with the grain yield for PCA and others were eliminated for developing MDS.

2.5. SOIL QUALITY INDEX (SQI)

Parr *et al.* (2012) found it imperative to develop a numerical relationship that could quantify different attributes of soil quality. They developed such a relationship as,

$$SQI = f\{SP, P, E, H, ER, BD, FQ, MI\}$$

Where, SP represents soil properties, P represent potential productivity, E represents Environmental factors, H represents health, ER represents erodibility, BD represents biological diversity, FQ represents food quality and MI represents management inputs.

There are mainly 3 steps outlined by Andrews *et al.* (2002) which includes (i) selection of MDS that best represents the soil function, (ii) score the MDS based on their performance in soil function and (iii) integrate the indicator by scoring to a comparable index of soil quality.

2.5.1. Methods to assess SQI

Mainly three methods are employed in assessment of SQI (Mukherjee and Lal, 2014) which includes (i) simple additive SQI (ii) weighted additive SQI (iii) statistically modelled SQI.

2.5.1.2. Simple additive SQI

Simple additive method is employed by giving threshold values to the soil parameters based on expert opinion and literature review. The individual index of each site is then summed up to obtain the total SQI. This method was outline by Amacher *et al.* (2007).

$$SQI = \sum \text{individual soil parameter index value}$$

The scaled SQI of individual site is then computed by the equation,

$$SQI = (\sum SQI - SQI_{min}) / (SQI_{max} - SQI_{min})$$

Where, SQI_{min} represents minimum recorded value for SQI and SQI_{max} represents maximum recorded value for SQI.

2.5.1.3. Weighted additive SQI

In weighted additive SQI, soil parameters are divided in to three functions, (i) more is better (like AWC, WSA etc.) (ii) less is better (like BD) (iii) optimum (like pH, EC) and unit less scores are given from 0 to 1 in such a way that for more is better highest observed value is given score 1 and in less is better, score one is given to lowest observed value.

$$SQI = [(\text{Weight } 1) \times RDC] + [(\text{Weight } 2) \times WSC] + [(\text{Weight } 3) \times NSC]$$

Where RDC was root development capacity, WSA was water storage capacity and NSC was nutrient storage capacity

This equation for SQI was formulated by Fernandes *et al.* (2011). The weights are given according to their importance in soil management.

2.5.1.3. Statistical model

In statistical model, principal component analysis (PCA) was used to estimate SQI by creating a minimum data set (MDS).

PCs receiving high Eigen values best represents the systems, so PCs having more than one Eigen value were considered for developing MDS (Brejda *et al.,* 2000). For each PC, the variable receiving highest loading factor and the ones receiving weights within 10 per cent of the highest weighted or loaded were retained (Andrews *et al.*, 2002).

If more than one variable is retained in a particular PC, correlation is worked out and if not correlated, then each of them is considered important and retained in MDS and if correlated, the one with highest loading factor or weight is considered in MDS (Andrews and Carroll, 2001).

Armenise *et al.* (2013) while developing a soil quality index in different management using PCA followed by integrating to a weighted additive SQI found that SQI was not significantly related with yield pointing out the fact that other indicators not used in the particular study being more influential upon yield.

After arriving at the MDS, weightage is given for each variable from the PCA results as the ratio of % variance to the total % variance of the PC group whose Eigen value is greater than one. SQI is calculated from the equation,

$$SQI = \sum Wi \times Si$$

where Wi is the weightage given from PCA analysis and Si is the score given as per the weighted additive method mentioned in section 2.5.1.2.

According to Mukherjee and Lal (2014), the PCA method largely avoids the biasness and selection of MDS help to reduce the data redundancy unlike other methods where reliance on literature and expert opinion were more.

A positive correlation was observed between SQI developed from MDS and wheat yield in wheat-maize cropping system in China (Li *et al.,* 2019).

2.6. NUTRIENT INDEX AND LAND QUALITY INDEX (LQI)

For the comparison of soil fertility of one area to another, a single value for each nutrient was essential. Nutrient index is such a measurement.

Parker *et al.* (1951) felt a need of generating a general picture of nutrient status for a state or a country to aid research and also to record the regular trends in the fertility of soil. For the same, they developed an index to assess the soil fertility which categorizes the soil into various classes of soil fertility. It indicates the overall fertility of an area. This method is widely adopted.

Ravikumar (2013) computed the nutrient index values (NIV) for organic carbon, available phosphorus and potassium in Varahi river basin of Karnataka.

Mandal *et al.* (2001) developed crop specific land quality index for sorghum where LQI is developed as a function of soil quality index (SQI) and climate quality index (CQI) and LQI obtained significant correlation with sorghum yield.

Kumar *et al.* (2015) concluded that soil organic carbon as a the most reliable and differentiating attribute which can be used alone or in combination with other attributes for the identification of land quality. They adapted the criteria of Shalimadevi (2006) for the rating of land quality from SOCS.

Land quality index assessment by using multi-criteria decision analysis was conducted by Kumar and Jhariya (2015) in Chhattisgarh for Patan block. They used organic matter content, soil texture, soil depth, pH, soil P, soil K, runoff potential, geomorphology, slope and land use to assess the LQI by applying remote sensing and GIS.

2.7. REMOTE SENSING, GIS AND SOIL MAPPING

Remote sensing is the procurement of data about certain objects or phenomena by gathering information from a device which is not in direct contact with the subject under consideration. (Karale *et al.*, 1982)

Mougenot *et al.* (1993) believed remote sensing to be an important tool in mapping and survey of problem soil. The salt affected soils of Etah, Aligarh, Mathura and Mainpuri have been mapped by Verma *et al.* (1994)

Geographical information system is considered as a useful tool for smooth access, retrieval of bulky data for manipulation which is difficult to manage manually. (Mandal and Sharma, 2010). Mishra *et al.* (2016) used the geo referenced samples to prepare soil fertility map of a district in Odisha for easy understanding, planning and sustainable management.

The efficiency of the soil survey has been improved by scientific advancement in the field of remote sensing, GIS and GPS. Integration of satellite data with ground level observations and non-spatial attribute data can be used to facilitate development of a particular region in remote sensing, GPS and GIS environment. (Sahu *et al.,* 2015) They also suggested it to be cost effective and time saving for sustainable management.

GPS helped to understand the fertility status spatially and temporally and also to formulate site specific balanced fertilizer recommendation. (Pulakeshi *et al.*, 2012)

Dongare *et al.* (2013) opined that remote sensing and GIS had immensely helped in appraisal of land resources. The utility of remote sensing and geographic information system were found to be effective in terrain characterization and soil resource inventory (Gangopadhyay *et al.,* 2015)

Sahu *et al.* (2017) suggested remote sensing, GIS and global positioning system (GPS) as efficient tools in soil and water resource management while studying the morphometric analysis of central India.

Materials and Methods

3. MATERIALS AND METHODS

The study entitled 'Assessment of soil quality in the post-flood scenario of AEU 4 in Kottayam district of Kerala and generation of GIS maps', was carried out at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2018-2020 to assess the post-flood soil quality and to generate GIS maps. The following materials and methods were employed for the execution of the research work.

3.1 SURVEY, COLLECTION AND CHARACTERIZATION OF SOIL

3.1.1. Details of sampling locations

Samples were collected from AEU 4, which represents Kuttanad region of Kerala. Samples were collected from 18 panchayats in 4 different blocks including Kaduthuruthy, Ettumanoor, Madappaly and Vaikom blocks in various parts of AEU 4 in Kottayam district. These panchayats were selected based on the information provided by the respective Krishi bhavans on the severity of flood.

3.1.2. Details of survey

Basic details of individual farmers were collected based on a pre-designed questionnaire including holding size, crops cultivated, nutrient management practices followed (Appendix I) and depth of sand/ silt/ clay deposition

3.1.3. Collection of samples

Sampling was done in the month of April, 2019 after the floods which affected major parts of the state. Seventy-five geo-referenced soil samples were collected from 18 different panchayaths of Ettumanoor, Madapally, Kaduthuruthy and Vaikom blocks of AEU 4 in Kottayam district. Surface soil samples (0 - 15 cm) and core samples were collected from the flood affected areas for further analysis. Geographical coordinates were recorded for each site for the purpose of mapping.

Table 1. Geographical coordinates of the sampling points in AEU 4 of Kottayam district

Sl no.	Name of panchayat	No. of samples	Sampling points	Latitude (° N)	Longitude (° E)
1	Kumarakom	4	1	9.594244	76.431109
			2	9.577924	76.406422
			3	9.566681	76.435550
			4	9.616433	76.417626
2	Thiruvarp	2	5	9.592427	76.474135
			6	9.575274	76.471935
3	Neendoor	4	7	9.659152	76.504426
			8	9.685114	76.499698
			9	9.673448	76.497090
			10	9.663499	76.471197
4	Arpookara	4	11	9.642800	76.490715
			12	9.642026	76.414941
			13	9.647938	76.448151
			14	9.631111	76.506664
5	Ayamanam	5	15	9.611060	76.496165
			16	9.631485	76.465628
			17	9.634026	76.410535
			18	9.618872	76.479472
			19	9.631807	76.440073
6	Kaduthuruthy	4	20	9.777818	76.485691
			21	9.759742	76.506707
			22	9.738221	76.475926
			23	9.762551	76.476541
7	Thalayolaparambu	5	24	9.793070	76.459431
			25	9.782649	76.450371
			26	9.775713	76.444116
			27	9.754057	76.440087
			28	9.763061	76.443639
8	Mulakkulam	4	29	9.812320	76.503000
			30	9.831495	76.484125
			31	9.805181	76.486641
			32	9.830628	76.501167
9	Kallara	3	33	9.733785	76.448954
			34	9.713707	76.461851
			35	9.692934	76.472174

(continued….)

Table 1. Geographical coordinates of the sampling points in AEU 4 of Kottayam district (continued)

Sl no.	Name of panchayat	No. of samples	Sampling points	Latitude (° N)	Longitude (° E)
10	Velloor	4	36	9.819035	76.440143
			37	9.808787	76.446350
			38	9.817744	76.460657
			39	9.832157	76.462208
11	Vazhapally	2	40	9.461840	76.512661
			41	9.470083	76.556411
12	Paippad	4	42	9.419690	76.564399
			43	9.422465	76.519898
			44	9.425538	76.546987
			45	9.425479	76.580232
13	Thrikodithanam	4	46	9.438328	76.568850
			47	9.445830	76.577420
			48	9.451387	76.590708
			49	9.452699	76.568658
14	T.V.Puram	6	50	9.715266	76.384349
			51	9.707025	76.385490
			52	9.705221	76.394138
			53	9.714130	76.398706
			54	9.694691	76.396024
			55	9.698150	76.384015
15	Udayanapuram	6	56	9.761779	76.419332
			57	9.778434	76.403709
			58	9.779021	76.381253
			59	9.772778	76.428611
			60	9.771428	76.415499
			61	9.751327	76.421008
16	Vechoor	4	62	9.666539	76.438120
			63	9.675816	76.414256
			64	9.678586	76.436365
			65	9.657778	76.413424
17	Thalayazham	5	66	9.731939	76.419763
			67	9.712209	76.423423
			68	9.698929	76.412636
			69	9.699424	76.429296
			70	9.721740	76.422738

(continued…)

Table 1. Geographical coordinates of the sampling points in AEU 4 of Kottayam district (continued)

Sl no.	Name of panchayat	No. of samples	Sampling points	Latitude (° N)	Longitude (° E)
18	Chempu	5	71	9.830116	76.385796
			72	9.813318	76.421619
			73	9.803333	76.425556
			74	9.816524	76.406102
			75	9.817745	76.389040

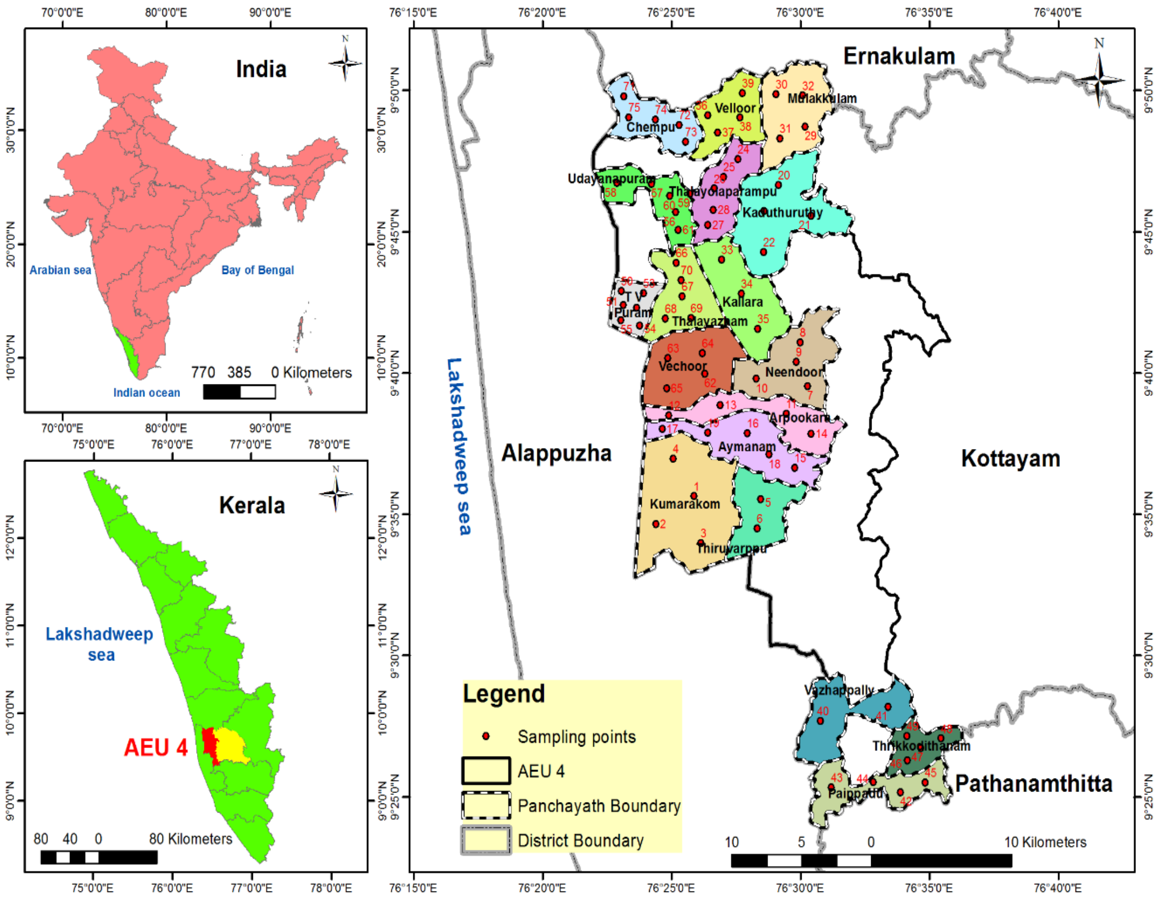


Figure 1. Location map of the study area indicating sampling points

3.1.4. Weather parameters

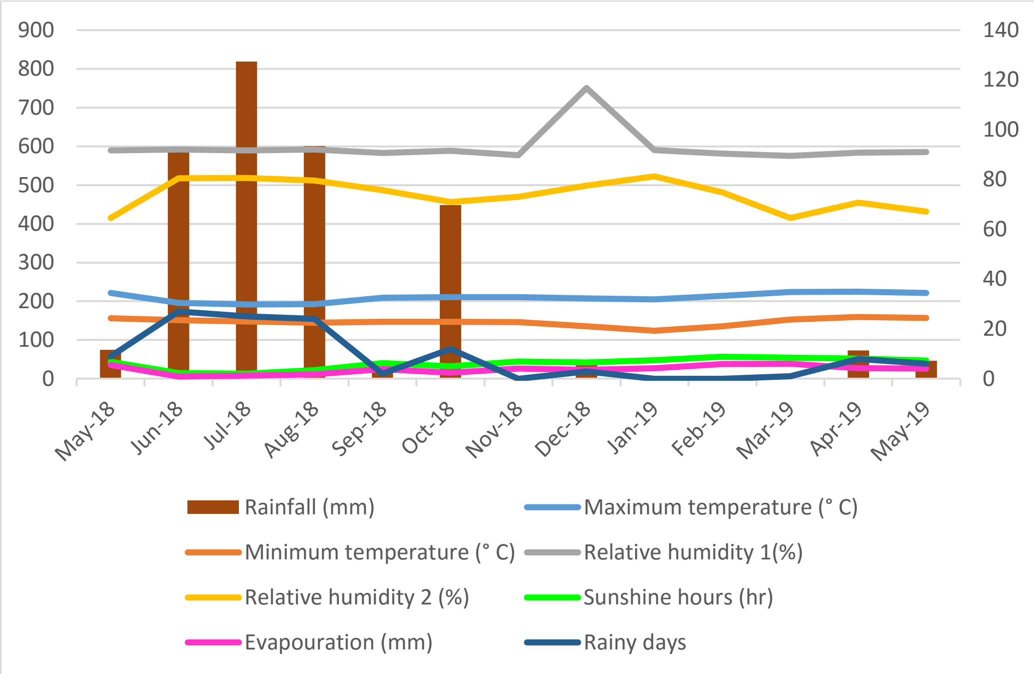


Figure 2. Monthly mean of weather parameters in Kottayam (May 2018-May 2019)

Table 2. Deviation in rainfall and no. of rainy days during 2018 from the average monthly data over the previous ten years

Month	Average rainfall (mm) 2008-2017	Rainfall (mm) 2018	Deviation in rainfall (mm)	Average no. of rainy days 2008-2017	No. of rainy days (2018)	Deviation in no. of rainy days
January	15.80	0	-15.80	0.6	0	-0.6
February	12.48	0	-12.48	1.3	0	-1.3
March	71.36	27.70	-43.66	3.5	2	-1.5
April	117.51	163.1	+45.59	7.1	11	+3.9
May	177.85	74.60	-103.25	9.9	9	-0.9
June	523.85	595.7	+71.85	22.2	27	+4.8
July	398.64	818.7	+420.06	22.2	25	+2.8
August	275.24	600.4	+325.16	16.6	24	+7.4
September	257.43	35.40	-222.03	14.8	2	-12.8
October	257.66	448.6	+190.94	12.4	12	-0.4
November	163.72	0	-163.72	8.2	0	-8.2
December	46.67	40.20	-6.470	2.7	3	+0.3

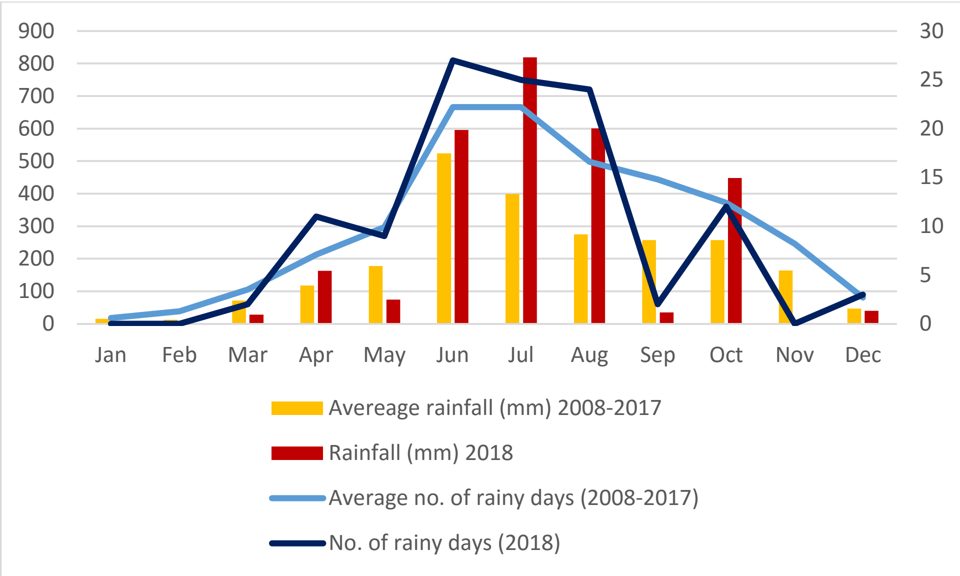


Figure 3. Comparison of rainfall and no. of rainy days in the year 2018 to the mean values for last 10 years (2008-2017)

3.1.5. Processing of samples

The collected soil samples were air dried in shade at room temperature. Samples were then crushed with the help of a wooden hammer and sieved through a 2 mm sieve and were then stored in a polythene bag until further analysis.

3.1.6. Characterization of samples

The collected samples were characterized for various physical, chemical and biological attributes.

(i) Physical attributes – included bulk density, particle density, porosity, maximum water holding capacity, soil moisture. textural analysis, depth of sand/silt/clay deposition and aggregate analysis

(ii) Chemical attributes – included soil reaction, electrical conductivity, soil organic carbon, available primary and secondary nutrients and micronutrient (boron)

(iii) Biological attribute – acid phosphatase activity

3.1.6.1. Analytical procedures followed for the characterization of soil samples

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

Parameter	Method	Reference
Bulk density	Undisturbed core sample	Black *et al.* (1965)
Particle density	Pycnometer method	Vadyunina and Korchagioa (1986)
Porosity	Calculated using BD and PD values	Danielson and Sutherland (1986)
Maximum Water Holding Capacity (WHC)	Core method	Dakshinamoorthy and Gupta (1968)
Aggregate analysis	Wet sieving	Yoder (1936)
Soil texture	Hydrometer method	Bouyoucos (1962)
pH	Soil water suspension in 1:2.5 ratio by pH meter (w/v)	Jackson (1958)
Electrical conductivity (EC)	Soil water suspension in 1:2.5 ratio by pH meter (w/v)	Jackson (1958)
Organic carbon	Wet oxidation method	Walkley and Black (1934)
Available nitrogen	Alkaline permanganometry	Subbiah and Asija (1956)
Available phosphorus	Bray No. I extraction and spectrometry	Bray and Kurtz (1945)
Available potassium	Extraction with neutral normal ammonium acetate followed by flame photometry	Jackson (1958)

Parameter	Method	Reference
Available calcium and magnesium	Extraction with neutral normal ammonium acetate followed by EDTA titration	Hesse (1971)
Available sulphur	$CaCl_2$ extraction followed by spectrometry	Massoumi and Cornfield (1963)
Available boron	Hot water extractible followed by spectrometry	Gupta (1972)
Acid phosphatase activity	p-nitophenol produced was estimated calorimetrically (using MUB as buffer)	Tabatabai and Bremner(1969)

3.2. SETTING UP OF A MINIMUM DATA SET (MDS) FOR ASSESSMENT OF SOIL QUALITY

To determine the SQI, several steps have to be followed which include selection of minimum data set (MDS) which was carried out by employing principal component analysis (PCA), scoring of MDS and integration of the scores to arrive at the soil quality index. PCA is based on the assumption that PCs receiving higher values best represent the system attributes

Only the principal components with Eigen values greater than one was examined. Among each PC, the one having highest factor loading was identified. The highly weighted variables were selected from each PC which showed loading values within 10 per cent of highest factor loading were retained. If more than one variable is retained from any of the PC, correlation between them was considered to check their redundancy. (correlation coefficient more than 0.6) Among the well correlated variables in a PC, the ones with highest values of correlation coefficient were selected in MDS (Andrews *et al.,* 2002).

3.3. FORMULATION OF SOIL QUALITY INDEX (SQI), LAND QUALITY INDEX (LQI) AND NUTRIENT INDEX (NI)

3.3.1. Soil quality index

The attributes which were selected as MDS were assigned with appropriate weights which was determined by soil conditions, cropping pattern and agro-climatic conditions as suggested by Singh *et al.* (2017). Each attribute was then categorized into various classes (class I-very good status, class II-good status, class III-poor status, class IV-very poor status) and assigned scores as 4, 3, 2 and 1. (Kundu *et al.,* 2012) The scores were the combined to obtain an overall weighted additive soil quality index by using a formula

$$SQI = \sum_{i=1}^{n} Wi \times Si$$

Where Wi represents the weightage factor and Si represent the score of the indicator. The weighing factors.

The relative soil quality index (RSQI) is calculated as the outlined by Karlen and Stott, (1994)

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

Where SQI is the calculated value of soil quality index and SQI_m is the maximum theoretical value of SQI. Each sampling location were then rated on the basis of RSQI values as low (RSQI < 50 per cent), medium (RSQI 50 to 70 per cent) and good (RSQI > 70 per cent) (Kundu *et al.,* 2012).

3.3.2. Land Quality Index

LQI was measured based on soil organic carbon stock (SOCS) as indicated by Shalimadevi (2006**)** and SOCS was analysed by the equation suggested by Batjes (1996) and is expressed in Mg ha^{-1}.

$$SOCS = \text{Soil organic carbon (\%)} \times \text{bulk density (Mg m}^{-3}) \times \text{soil depth (m)} \times 100$$

The value obtained were then represented in kg m^{-2} for the interpretation of LQI as given below

Table 4. Ratings for Land quality index

SOC Stock (Kg/m^2)	LQI
<3	Very low
3-6	Low
6-9	Medium
9-12	Moderate
12-15	High
>15	Very high

3.3.3. Nutrient Index

Nutrient index is calculated by the equation suggested by Parker *et al.* (1951)

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

Where N_l, N_m and N_h stands for number of samples falling in the category of low, medium and high nutrient status respectively. The rating chart by Ramamoorthy and Bajaj (1969) is given in Table 5.

Table 5. Nutrient index rating

Nutrient index	Range	Interpretation
I	Below 1.67	Low
II	1.67 – 2.33	Medium
III	Above 2.33	High

3.6. PREPARATION OF GIS MAPS

The analysed data of various chemical parameters like pH, organic carbon, available primary and secondary nutrients, boron, computed values for RSQI and LQI were then utilized for preparing thematic maps using ArcGIS 10.5.1 software through interpolation.

Inverse distance weighted (IDW) method, a spatial analyst tool was used as the interpolation tool. It works on the assumption that the variable being mapped decreases in influence with distance from its sampled location. The IDW technique computes an average value for unsampled locations using values from nearby weighted locations. Weights are calculated using an equation based on the distance between the known and unknown locations and the total number of sampling points (Ogbozige *et al.,* 2018)

The base map of AEU 4 in Kottayam district with the boundaries of sampled panchayats was imported to the ArcGIS software. The analysed data for the attributes along with the geo coordinates of the sampling pointes were entered in Microsoft excel which was then converted to a CSV (comma delimited) file which was also imported to ArcGIS mapping software.

IDW was selected as the spatial analyst tool. Longitude, latitude and soil attribute values were selected as x, y, and z respectively and boundaries of the panchayats was selected as the processing extend in the IDW and the data was interpolated. The map obtained as the output were classified to different classes and colours were allocated for each class.

3.7. STATISTICAL ANALYSIS

Correlation**s** were worked out in between various physical, chemical and biological parameters by the method suggested by Panse and Sukatme (1978).

Results

4. RESULTS

The results obtained during the investigation are presented here.

4.1. SURVEY, COLLECTION AND CHARACTERIZATION OF SAMPLES

4.1.1. Survey

A survey was conducted during sampling period based on a pre-designed questionnaire. The basic details obtained about the crops, nutrient management and holding size are provided in Table 6. Most of the area were under rice based cropping system. Vegetables, banana, coconut and nutmeg were the other main crops. Nutmeg was found to be cultivated in some parts of Mulakkulam and Udayanapuram panchayats. Majority of the farmers were small to marginal land holders and followed a conventional method of farming. They preferred mixed fertilizers for vegetables and banana. Organic practice was mainly followed for nutmeg. Paddy growers in many parts of the area reported a hike in paddy yield after flooding. Nutmeg growers faced severe problem of wilting. There was no uniformity for the deposition of sand/ silt or clay but in some parts of the AEU near water source, deposition had occurred up to 3 inches was observed by the farmers.

Proper practice of liming was followed by majority of the farmers based on the suitable guidelines from the officials. Dolomite was also used as the liming material since they are cheaper. Urea, potash and factomphos were applied in 2-3 splits in paddy field.

The organic farmers used FYM, poultry manure, bone meal, neem cakes etc. Use of liquid organic manures like jeevamruth and panchakavya were also applied especially by vegetable farmers. Those having biogas plants were using biogas slurry as manure in the field. Only few farmers were following completely organic method for farming (5.33 per cent). Many farmers used mixed fertilizers for vegetables and banana. Emerging trend of using mixed fertilizers like 18-18-18 in banana was also reported.

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

Particulars	No. of farmers	Percentage
Crop		
1. Paddy	38	51.0
2. Banana	26	48.0
3. Vegetables	20	26.0
4. Nutmeg	15	20.0
5. Tapioca	10	13.0
6. Coconut	15	20.0
7. Others	9	12.0
Nutrient Management		
1. INM	16	21.0
2. Conventional	55	73.0
3. Organic	4	5.00
Size of holding		
1. < 2 ha	71	94.0
2. 2– 4 ha	2	3.00
3. > 4 ha	2	3.00

4.1.2. Characterization of soil samples

Soil quality was assessed by analysing various physical, chemical and biological parameters of the samples collected from the AEU 4 of Kottayam district. The analysed data was then used for setting up of MDS and SQI.

4.1.2.1. Physical attributes

Samples collected from various panchayats were analysed for physical parameters like bulk density, particle density, porosity, soil texture, maximum water holding capacity, soil moisture, aggregate analysis, depth of sand/silt/clay deposition and their mean, standard deviation and range were calculated panchayat wise for the interpretation of results.

4.1.2.1.1. Bulk density

The bulk density values of soil samples from various panchayats in general varied from 1 Mg m^{-3} to 2 Mg m^{-3} with a mean value of 1.20 Mg m^{-3}. The BD for 34.67 per cent of samples ranged from 0.79 Mg m^{-3} to 1.47 Mg m^{-3} which was very low. The lowest value was reported at Kallara panchayat (0.79 Mg m^{-3}) followed by Kaduthuruthy panchayat with a value of 0.91 Mg m^{-3} (Table 7).

4.2.1.2. Particle density

AEU in general had a particle density of 2.07 Mg m^{-3} as the mean value and the values ranged from 1.37 to 2.60 Mg m^{-3}. The highest mean value was reported at Thrikodithanam (2.34 Mg m^{-3}) and lowest mean value was recorded at Vechoor followed by Kallara with a mean value of 1.70 Mg $m^{-3}$and 1.72 Mg m^{-3} respectively (Table 7).

4.2.1.3. Porosity

Porosity of the AEU ranged widely from 14.6 per cent to 73.1 per cent with a mean value recorded as 42.0 per cent. The maximum mean value for percent pore space was found at Kaduthuruthy (54.6 per cent) and lowest mean value was reported at T.V. Puram panchayat (30.2 per cent) (Table 7).

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

Panchayat	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Kumarakom	1.18 ± 0.10	1.10 - 1.33	2.20±0.30	1.92-2.60	45.7±6.80	40.9-55.8
Thiruvarp	1.08 ± 0.02	1.06 - 1.09	2.05±0.07	2.00-2.10	47.5±2.84	45.5-49.5
Neendoor	1.32 ± 0.10	1.19 - 1.44	2.17±0.06	2.09-2.24	38.8±5.68	31.1-44.7
Arpookara	0.95 ± 0.12	0.78 - 1.03	2.04±0.23	1.74-2.26	53.3±3.38	48.2-55.3
Aymanam	1.08 ± 0.09	1.01 - 1.24	2.15±0.32	1.85-2.60	49.2±3.66	45.4-53.0
Kaduthuruthy	0.91 ± 0.25	0.54 - 1.07	2.00±0.02	1.96-2.01	54.6±12.6	46.5-73.1
Thalayolaparambu	1.29 ± 0.05	1.21 - 1.33	2.13±0.13	2.30-2.34	39.6±2.54	36.9-43.1
Mulakkulam	1.25 ± 0.37	0.85 - 1.56	2.10±0.06	2.03-2.17	40.7±17.0	25.0-50.3
Kallara	0.79 ± 0.07	0.72 - 0.86	1.72±0.14	1.56-1.83	54.0±8.14	44.9-60.7
Velloor	1.30 ± 0.27	1.07 - 1.59	2.16±0.14	1.82-2.44	39.1±15.0	19.8-52.4
Vazhapally	1.24 ± 0.13	1.15 - 1.33	1.82±0.02	1.80-1.83	31.6±7.81	23.1-37.2
Paippad	1.22 ± 0.18	1.06 - 1.37	2.22±0.26	1.88-2.46	45.3±3.99	41.7-50.9
Thrikodithanam	1.15 ± 0.06	1.06 - 1.18	2.34±0.06	2.25-2.38	50.8±1.46	49.6-52.9
TV Puram	1.47 ± 0.08	1.37 - 1.55	2.13±0.19	1.91-2.45	30.2±9.12	18.9-441
Udayanapuram	1.34 ± 0.16	1.01 - 1.41	2.09±0.17	1.95-2.42	35.6±8.16	27.7-49.3
Vechoor	1.04 ± 0.22	0.82 - 1.31	1.70±0.25	1.37-1.93	39.0±5.04	32.1-44.2
Thalayazham	1.22 ±0.25	0.99 - 1.58	1.91±0.41	1.44-2.56	34.8±13.6	14.6-50.0
Chempu	1.33 ±0.10	1.24 - 1.44	2.14±0.20	1.89-2.43	37.6±7.58	29.1-49.0
AEU	1.20±0.22	0.72-1.59	2.07±0.25	1.37-2.60	42.0±10.6	14.6-73.1

4.2.1.4. Particle size distribution

Particle size distribution of various samples were studied and the per cent of various soil separates were found out. The sand sized particles varied from 33.8-78.8 per cent. The sand content recorded a mean value of 61.0 per cent in the AEU. The mean value for sand was maximum at T.V. Puram panchayat (60.5 per cent) and minimum at Kallara and Paippad panchayat (48.8 per cent) (Table 8). The silt content was found to be 13.9 per cent and ranged from 5.00-40.0 per cent in the AEU. The highest mean value of 25.1 per cent was recorded at Thiruvarp panchayat and lowest mean at Thalayazham panchayat (7 per cent) (Table 8). The clay content in the AEU recorded a value of 31.2 per cent where the mean values varied from 16.2 per cent in Thiruvarp to 33.7 per cent in Kaduthuruthy (Table 8).

Table 8. Per cent sand, silt and clay in post-flood soils of AEU 4 in Kottayam district

Panchayat	% Sand		% Silt		% Clay	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Kumarakom	71.3±6.46	63.8-78.8	7.52±5.00	5.00-15.0	21.2±7.07	16.2-31.2
Thiruvarp	58.8±7.07	53.8-63.8	25.0±7.07	20.0-30.0	16.2	16.2
Neendoor	61.3±15.6	38.8-73.8	15.0±10.8	5.00-30.0	23.7±6.46	16.2-31.2
Arpookara	60.1±6.3	53.8-68.8	13.8±4.79	10.0-20.0	26.2±4.08	21.2-31.2
Aymanam	63.8±7.07	53.8-63.8	8.50±6.52	5.00-20.0	27.7±5.48	18.7-31.2
Kaduthuruthy	57.6±13.2	38.8-68.8	8.75±4.79	5.00-15.0	33.7±13.23	21.2-51.2
Thalayolaparambu	58.8±11.2	43.8-73.8	13.0±7.58	5.00-20.0	28.2±6.71	21.2-36.2
Mulakkulam	52.6±23.2	43.8-73.8	19.4±20.5	7.50-50.0	28.1±12.5	18.7-46.2
Kallara	48.8±13.2	33.8-58.8	21.7±7.64	15.0-30.0	29.5±5.77	26.2-36.2
Velloor	60.1±18.0	33.8-73.8	18.8±15.0	5.00-40.0	21.2±1.08	16.2-26.2
Vazhapally	56.3±10.6	48.8-63.8	15.0±7.07	10.0-20.0	28.7±17.7	16.2-41.2
Paippad	48.8±15.8	33.8-68.8	22.5±13.2	5.00-35.0	28.7±5.00	26.2-36.2
Thrikodithanam	73.8±4.08	73.8-78.8	5.00	5.00	21.2±4.08	16.2-26.2
TV Puram	60.5±15.1	38.8-78.8	13.3±9.31	5.00-30.0	26.2±8.94	16.2-26.2
Udayanapuram	53.8±10.5	38.8-63.8	22.1±10.5	15.0-40.0	24.1±6.00	16.2-31.2
Vechoor	63.8±10.8	48.8-73.8	13.8±6.29	5.00-20.0	22.5±6.29	16.2-31.2
Thalayazham	69.8±8.22	58.8-78.8	7.00±2.74	5.00-10.0	23.2±8.37	16.2-36.2
Chempu	70.8±9.08	58.8-78.8	9.00±5.48	5.00-15.0	20.2±4.18	16.2-26.2
AEU 4	61.0±13.0	33.8-78.8	13.9±9.95	5.00-40.0	25.1±7.6	16.2-51.2

4.2.1.5. Depth of sand/silt/clay deposition

There was no uniform pattern in the distribution of sand/silt/clay deposition. Paddy field in many areas like Kallara, Vechoor, Aymanam, Kaduthuruthy recorded varying amounts of deposits in less than 5 cm thickness. Some areas of Velloor, Mulakkulam, T.V. Puram also witnessed certain quantities of silt deposition in not more than 3 cm. Some farmers observed only a layer of deposits in their field. Removal of the sediments were not required as only lower levels were deposited. They incorporated the deposits in the field itself before the next crop.

4.2.1.6. Maximum water holding capacity

The maximum water holding capacity of the entire area was having a mean value of 41.3 per cent and varied from 20.6 per cent to 68.8 percent in various parts. The water holding capacity was found to be maximum at Kaduthuruthy panchayat with a mean value of 56.7 per cent and lowest recorded value was at T.V. Puram panchayat with a mean value of 32.6 percent.

4.2.1.7. Soil moisture

In general, the per cent of soil moisture in AEU was found to be 20.6 per cent and it ranged from 3.11 per cent to 72.3 per cent in the AEU. Soil moisture content was highest at Kallara panchayat recording 55.5 percent and lowest per cent of 7.47 was recorded at Velloor panchayat (Table 9).

Table 9.WHC and soil moisture in post-flood soils of AEU 4 in Kottayam district

Panchayat	WHC (%)		Soil moisture (%)	
	Mean±SD	Range	Mean±SD	Range
Kumarakom	35.9±4.75	28.8-38.7	15.5±13.5	6.71-35.1
Thiruvarp	47.8±2.88	45.8-49.9	15.8±14.4	5.66-25.9
Neendoor	34.3±2.55	32.8-38.1	9.43±1.42	7.55-11.0
Arpookara	49.6±7.72	45.3-61.2	32.4±2.70	30.1-35.1
Aymanam	44.8±4.64	39.7-51.9	20.9±10.3	8.10-30.7
Kaduthuruthy	56.7±8.06	52.4-68.8	30.1±45.0	20.6-48.6
Thalayolaparambu	36.2±2.53	34.2-40.4	10.3±2.20	8.53-12.7
Mulakkulam	40.5±19.4	23.7-57.6	23.3±26.1	10.2-64.1
Kallara	66.9±1.52	65.6-68.6	55.5±25.6	26.0-72.3
Velloor	38.9±14.9	20.6-51.1	7.47±4.85	3.11-11.3
Vazhapally	38.4±3.31	36.1-40.8	10.3±3.50	7.90-12.7
Paippad	45.0±10.4	36.0-54.0	19.1±8.20	12.0-26.2
Thrikodithanam	39.5±2.61	36.0-41.5	11.8±3.20	9.52-16.3
TV Puram	32.6±3.95	27.9-36.6	12.9±11.6	5.24-27.9
Udayanapuram	34.5±4.51	30.6-43.4	21.5±10.3	14.8-42.4
Vechoor	45.9±9.04	35.4-54.5	25.7±18.5	10.2-48.3
Thalayazham	39.0±11.0	26.8-50.7	14.2±4.58	8.39-18.9
Chempu	35.7±3.09	33.4-39.1	17.1±2.84	12.5-19.7
AEU 4	41.3±10.7	20.6-68.8	20.6±18.4	3.11-72.3

4.2.1.8. Aggregate analysis

Mean weight diameter and per cent water stable aggregates were calculated in aggregate analysis. The mean value recorded for MWD was 1.40 mm and for percentage water stable aggregates was 64.60 per cent for the entire area. From the study it was observed that lowest value of MWD and percentage water stable aggregates as 0.38 mm and 40.5 percent respectively in T.V. Puram and 2.66 mm and 79.87 percent respectively as highest values in Kallara and Neendoor. The mean and range of MWD and per cent water stable aggregates are presented in Table 10.

Table 10. Mean weight diameter (MWD) and percentage water stable aggregates in post-flood soils of AEU 4 in Kottayam district

Panchayat	MWD (mm)		% Water stable aggregates	
	Mean±SD	Range	Mean±SD	Range
Kumarakom	1.42±0.03	1.37-1.43	57.5±3.76	51.8-59.3
Thiruvarp	1.22±0.03	1.20-1.24	62.2±5.32	58.4-65.9
Neendoor	2.43±0.15	2.21-2.53	79.8±2.81	76.4-83.2
Arpookara	2.19±1.10	1.24-3.14	80.8±2.70	78.5-83.2
Aymanam	1.92±0.88	0.87-2.84	76.6±19.0	42.9-87.8
Kaduthuruthy	1.91±0.20	1.81-2.20	75.0±6.02	72.0-84.0
Thalayolaparambu	1.89±0.68	1.23-2.84	80.1±4.70	74.1-85.6
Mulakkulam	1.67±0.56	1.21-2.35	68.0±15.5	54.8-84.4
Kallara	2.66±0.17	2.56-2.86	79.2±2.37	77.8-81.9
Velloor	1.01±0.18	0.76-1.14	54.2±6.62	44.5-58.4
Vazhapally	2.27±0.14	2.17-2.37	75.5±7.02	70.5-80.5
Paippad	1.07±0.16	0.93-1.21	66.1±11.6	56.1-76.4
Thrikodithanam	0.91±0.39	0.57-1.25	54.9±8.16	47.9-62.0
TV Puram	0.38±0.03	0.43-0.41	40.5±3.35	37.9-44.8
Udayanapuram	1.23±0.27	0.95-1.55	67.2±11.6	54.6-80.5
Vechoor	0.77±0.17	0.65-1.02	53.2±7.49	44.7-61.7
Thalayazham	0.69±0.31	0.34-1.02	48.2±9.16	41.5-58.2
Chempu	1.11±0.33	0.54-1.34	59.8±10.2	41.5-65.3
AEU 4	1.40±0.74	0.34-3.14	64.6±15.0	37.9-87.8

4.2.2. Chemical attributes

4.2.2.1. pH

Acidity was observed in almost all parts of the AEU. The area had an average pH value of 5.18 where the values varied from 3.11 at Kallara to 7.3 at Neendoor and Chempu. The mean value of 3.48 was recorded to be the lowest which was in Kallara panchayat followed by 3.59 in Vechoor panchayat and the highest mean value at Mulakkulam (5.81) (Table 11).

4.2.2.2. Electrical conductivity

The AEU as a whole had a mean value of EC as 0.55 dS m^{-1}. Mean value for electrical conductivity was highest at Kallara panchayat where an EC value of 1.57 dS

m^{-1} was observed as well as lowest mean value was found to be at Thalayolaparambu which was 0.08 dS m^{-1}(Table 11).

4.2.2.3. Organic carbon

The area was found to be rich in organic carbon. The values for OC varied from 0.47 to 12.98 per cent with a mean value of 2.62 per cent. Kallara panchayat reported the highest mean for organic carbon as 8.68 per cent and the lowest organic carbon content was reported at Velloor panchayat as 1.03 per cent (Table 11).

Table 11. Soil pH, electrical conductivity, and organic carbon status in post-flood soils of AEU 4 in Kottayam district

Panchayat	Soil reaction		Electrical Conductivity (dS m^{-1})		Organic carbon (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Kumarakom	5.43±1.51	3.69-7.25	0.83±0.34	0.44-1.21	1.32±1.03	0.47-2.81
Thiruvarp	5.73±0.02	5.72-5.75	0.57±0.51	0.21-0.93	2.16±0.64	1.71-2.61
Neendoor	6.47±0.64	6.08-7.30	0.61±0.36	0.09-0.88	1.52±0.17	1.29-1.69
Arpookara	4.57±0.83	3.93-5.76	0.96±1.10	0.05-2.50	3.86±1.40	2.80-5.49
Aymanam	4.76±0.63	4.28-5.85	0.57±0.53	0.06-1.29	2.27±1.04	1.28- 3.99
Kaduthuruthy	4.69±1.15	3.85-6.36	0.98±1.14	0.23-3.90	5.12±2.47	2.61-7.80
Thalayolaparambu	5.15±0.32	5.15-5.98	0.08±0.03	0.06-0.14	1.73±0.70	1.10-2.79
Mulakkulam	5.81±0.58	5.02-6.40	0.33±0.35	0.07-0.82	1.59±0.46	0.92-1.92
Kallara	3.48±0.45	3.11-3.99	1.57±0.98	1.00-2.70	8.68±3.14	5.49-11.7
Velloor	5.57±0.43	4.96-5.96	0.11±0.07	0.05-0.21	1.03±0.25	0.74-1.35
Vazhapally	4.20±1.06	3.45-4.95	0.55±0.63	0.11-1.00	3.13±3.04	0.98-5.28
Paippad	5.77±0.77	4.98-6.58	0.38±0.58	0.09-1.25	1.66±0.78	1.05-2.81
Thrikodithanam	5.02±0.21	4.83-5.33	0.50±0.44	0.13-1.03	1.81±0.94	1.01-2.97
TV Puram	5.73±1.06	4.30-6.96	0.32±0.34	0.10-0.98	1.14±0.43	0.81-1.98
Udayanapuram	5.43±0.81	4.58-6.80	0.19±0.04	0.16-0.26	1.56±0.73	0.84-2.50
Vechoor	3.59±0.17	3.38-3.74	0.71±0.34	0.36-1.00	6.07±4.08	3.17- 12.1
Thalayazham	4.59±1.06	3.23-5.65	0.46±0.35	0.14-1.00	3.99±5.12	0.47-12.9
Chempu	5.80±1.19	4.72- 7.30	0.16±0.07	0.11-0.26	1.50±0.66	0.92-2.61
AEU 4	5.18±1.03	3.11-7.3	0.55±0.67	0.05-3.90	2.62±2.56	0.47-12.9

4.2.2.4. Available nitrogen

The mean value of available nitrogen estimated in soils of 18 panchayats representing the AEU is found to be 219.77 kg ha^{-1} and the values ranged from 75.26

to 1003.5 kg ha^{-1}. About 78.67 per cent observed to be in low fertility status and only 2.67 per cent as high. The mean value was highest at Kumarakom with a value of 382.59 kg ha^{-1}. The lowest mean value observed was 137.98 kg ha^{-1} in Velloor panchayat (Table 12)

4.2.2.5. Available phosphorus

Phosphorus content in soils of the AEU had a mean value of 51.26 kg ha^{-1} and the mean values ranged from 1.79 kg ha^{-1} at Kallara panchayat to 188.41 kg ha^{-1} at Thrikodithanam panchayat (Table 12).

4.2.2.6. Available potassium

The soils of AEU 4 in general had a mean potassium content of 279.25 kg ha^{-1}. The highest mean value was observed at Mulakkulam panchayat with a potassium status of 557 kg ha^{-1} and lowest at Vazhapally panchayat with a mean value of 100.8 kg ha^{-1} (Table 12).

Table 12. Available N, P and K status in post-flood soils of AEU 4 in Kottayam district

Panchayat	Available N (kg ha $^{-1}$)		Available P (kg ha $^{-1}$)		Available K (kg ha $^{-1}$)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Kumarakom	382±415	150-1003	33.4±28.8	2.28-62.8	229±172	56.0-448
Thiruvarp	232±44.4	200-263	24.1±18.6	10.9-37.3	207±118	123-291
Neendoor	269±238	137-627	47.9±31.3	21.7-86.3	285±88.0	179-392
Arpookara	257±81.0	163-351	10.5±10.3	0.57-24.2	291±138	89.6-380
Aymanam	193±40.3	150-250	25.1±24.2	7.07-67.0	237±155	78.4-425
Kaduthuruthy	351±92.8	238-439	19.0±33.1	1.14-68.5	288±109	134-392
Thalayolaparambu	156±11.2	150-175	68.5±27.0	22.0-90.2	181±68.3	145-302
Mulakkulam	197±71.2	100-250	61.6±52.8	11.9-136	557±657	44.8-1512
Kallara	342±19.2	326-364	1.79±0.17	1.60-1.94	362±186	190-560
Velloor	138±17.7	125-163	40.6±31.9	7.98-82.4	140±58.9	78.4-190
Vazhapally	213±160	100-326	6.50±5.97	2.28-10.7	101±31.7	123-78.4
Paippad	160±80.9	87.8-276	117±70.4	56.3-204	490±489	67.2-1064
Thrikodithanam	178±72.0	113-263	188±104	54.0-274	274±190	112-549
TV Puram	130±42.5	75.3-200	71.7±56.5	15.50-157	153±85.2	67.2-280
Udayanapuram	201±47.0	151-289	40.0±29.7	11.9-73.5	291±190	101-582
Vechoor	279±18.8	263-301	15.8±19.0	2.28-43.2	487±146	269-571
Thalayazham	220±107	138-376	59.0±60.1	2.74-157	296±417	44.8-1030
Chempu	176±32.0	151-226	41.6±19.1	13.0-65.0	166±95.2	78.4-280
AEU 4	220±130	75.3-1003	51.3±57.0	1.14-274	279±248	44.8-1515

4.2.2.7. Available calcium

Average calcium status of the AEU was obtained as 676 mg kg^{-1} and the lowest availability of calcium was reported as 435 mg kg^{-1} at Velloor and highest at Thiruvarp as 1070 mg kg^{-1} (Table 13).

4.2.2.8. Available magnesium

Status of magnesium in the AEU 4 was found to have a mean value of 206 mg kg^{-1} where the values ranged from 12 mg kg^{-1} to 1080 mg kg^{-1} in different panchayats. The lowest mean value recorded was at Velloor as 87.0 mg kg^{-1}followed by Paippad, Thrikodithanam and Vazhapally panchayat. The highest value was recorded at Kallara panchayat as 524 mg kg^{-1} (Table 13).

4.2.2.9. Available sulphur

Sulphur availability showed a medium to high status in various panchayats recording a mean value of 180.88 mg kg^{-1}. The values varied widely from 0.5 to 1230 mg kg^{-1}. The lowest mean value of 6.10 mg kg^{-1} was obtained at Thalayolaparambu panchayat and highest as 1024 mg kg^{-1} at Kallara panchayat (Table 13).

4.2.2.10. Available boron

Boron status of AEU 4 as a whole was found to be deficient (0.39 ppm). The mean value obtained was lowest at Udayanapuram panchayat recording a value of 0.11 mg kg^{-1} and highest at Kallara with 1.39 mg kg^{-1} boron. The mean values and range of each panchayat is furnished in Table 14.

Table 13. Available calcium, magnesium, and sulphur status in post-flood soils of AEU 4 in Kottayam district

Panchayat	Available Ca (mg kg^{-1})		Available Mg (mg kg^{-1})		Available S (mg kg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Kumarakom	970±597	360-1540	222±157	84.0-420	289±476	9.00-1000
Thiruvarp	1070±192	320-1820	204±33.9	180-228	38.0±6.36	33.5-42.5
Neendoor	645±192	360-780	156±49.0	84.0-192	42.5±43.3	2.50-104
Arpookara	605±213	460-920	387±280	96.0-720	265±463	5.00-959
Aymanam	504±235	260-840	151±127	48.0-336	70.3±102	5.00-241
Kaduthuruthy	770±540	340-1480	333±170	180-480	434±450	44.5-713
Thalayolaparambu	568±137	400-680	127±49.9	48.0-168	6.10±2.63	2.50-9.00
Mulakkulam	780±192	560-960	195±142	120-408	9.13±5.96	3.50-17.5
Kallara	713±291	440-1020	524±398	288-984	1024±204	794-1182
Velloor	435±138	320-620	87.0±20.5	60.0-108	13.6±14.3	4.50-35.0
Vazhapally	810±552	420-1220	108±136	12.0-204	615±869	0.5-1230
Paippad	585±422	260-1200	93.0±49.4	48.0-156	55.8±98.2	3.00-203
Thrikodithanam	695±548	240-1340	99.0±70.2	60.0-204	150±170	8.50-355
TV Puram	773±413	180-1380	160±81.6	48.0-252	72.5±154	2.50-387
Udayanapuram	620±377	260-1280	170±78.7	72.0-252	34.8±35.8	3.00-101
Vechoor	585±326	180-920	510±508	24.0-1080	459±503	18.5-965
Thalayazham	456±153	240-660	185±294	36.0-708	247±467	3.5-1079
Chempu	904±871	340-2420	125±52.0	36.0-168	11.6±7.71	6.00-24.5
AEU	676±409	180-1820	206±208	24.0-1080	181±343	0.5-1230

Table 14. Available boron status in post-flood soils of AEU 4 in Kottayam district

Panchayat	Boron (mg kg^{-1})	
	Mean±SD	Range
Kumarakom	0.42±0.18	0.29-0.69
Thiruvarp	0.54±0.07	0.50-0.59
Neendoor	0.39±0.08	0.27-0.49
Arpookara	0.57±0.25	0.28-0.78
Aymanam	0.48±0.15	0.38-0.75
Kaduthuruthy	0.60±0.20	0.32-0.74
Thalayolaparambu	0.44±0.13	0.31-0.64
Mulakkulam	0.38±0.10	0.29-0.50
Kallara	1.39±0.32	1.04-1.66
Velloor	0.27±0.24	0.07-0.62
Vazhapally	0.53±0.09	0.46-0.59
Paippad	0.23±0.09	0.16-0.36
Thrikodithanam	0.40±0.34	0.11-0.85
TV Puram	0.23±0.19	0.06-0.55
Udayanapuram	0.11±0.07	0.01-0.20
Vechoor	0.35±0.06	0.27-0.42
Thalayazham	0.20±0.11	0.06-0.35
Chempu	0.16±0.15	0.01-0.37
AEU	0.39±0.29	0.01-1.66

4.2.3. Biological attribute

4.2.3.1. Acid phosphatase activity

Activity of acid phosphatase enzyme was studied from the soils of flood affected areas of AEU 4. The activity in general was recorded as 28.1 µg of p-nitro phenol g^{-1} soil h^{-1} for the whole area where values varied from 2.36 to 157 µg of p-nitro phenol g^{-1} soil h^{-1}. The lowest value recorded was in T.V. Puram panchayat as 8.41 (µg of p-nitro phenol g^{-1} soil h^{-1}) and highest as 106 (µg of p-nitro phenol g^{-1} soil h^{-1}) at Kallara panchayat (Table 15).

Table 15. Activity of acid phosphatase in soils of Kottayam district (AEU 4) under post flood scenario in of

Panchayat	Acid Phosphatase (µg of p-nitrophenol g^{-1} soil h^{-1})	
	Mean±SD	Range
Kumarakom	26.4±13.9	12.2-45.5
Thiruvarp	34.0±21.4	18.8-49.1
Neendoor	33.4±10.9	23.5-49.0
Arpookara	32.6±15.6	13.2-48.5
Aymanam	33.1±18.3	8.27-52.5
Kaduthuruthy	60.0±28.5	24.9-92.5
Thalayolaparambu	15.1±1.91	12.9-17.6
Mulakkulam	32.4±9.56	20.6-43.4
Kallara	106±60.1	39.6-157
Velloor	13.6±4.82	8.00-19.4
Vazhapally	5.77±1.74	4.55-7.00
Paippad	21.8±21.0	8.91-53.2
Thrikodithanam	19.4±14.6	7.27-37.9
TV Puram	8.41±5.03	2.36-15.4
Udayanapuram	16.0±11.2	2.64-35.3
Vechoor	37.8±18.5	12.5-56.3
Thalayazham	33.0±37.1	5.00-94.5
Chempu	10.5±6.53	3.27-19.2
AEU 4	28.1±26.8	2.36-157

4.3. FORMULATION OF MINIMUM DATA SET AND SOIL QUALITY INDEX

4.3.1. Formulation of minimum data set (MDS)

Principal component analysis (PCA) was used for setting up of minimum data set. All the analysed soil attributes (20) except porosity were considered as vectors. An Eigen value greater than one was obtained for six principal components which explained a variance of 35.4 per cent, 12.1 per cent, 8.3 per cent, 7.4 per cent, 5.5 per cent and 5.1 per cent respectively (Table 16)

Only the highly weighted variables (within 10 per cent of the highest factor loading) within each PC were retained. The correlation between variables were worked out if more than one variable was retained in a PC. The one with highest loading factor was retained for the MDS if they were significantly correlated ($r > 0.6$).

Table 16. Result of principal component analysis (PCA)

	PC1	PC2	PC3	PC4	PC5	PC6
Eigen values	**7.085**	**2.422**	**1.664**	**1.475**	**1.108**	**1.028**
Proportion	0.354	0.121	0.083	0.074	0.055	0.051
Cumulative Proportion	0.354	0.475	0.559	0.632	0.688	0.739
Eigen vectors						
	PC1	PC2	PC3	PC4	PC5	PC6
pH	-0.244	0.113	0.441	-0.092	-0.055	-0.115
EC	0.252	-0.104	0.123	0.040	0.112	-0.375
OC	**0.323**	-0.160	-0.033	0.123	-0.063	0.089
Available N	0.192	-0.057	0.270	-0.109	0.028	**-0.459**
Available P	-0.137	-0.014	0.192	0.194	**0.530**	0.274
Available K	0.128	-0.189	0.282	0.212	-0.295	**0.430**
Available Ca	0.038	-0.044	**0.649**	0.193	0.005	-0.152
Available Mg	0.275	-0.230	0.085	0.146	-0.235	0.091
Available S	**0.303**	-0.199	-0.045	0.116	-0.084	-0.070
Available B	0.268	0.035	0.072	-0.117	0.105	-0.194
Eigen vectors						
	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
Acid phosphatase	0.281	0.013	-0.008	-0.059	0.127	0.155
Bulk density	**-0.310**	-0.120	0.016	0.053	-0.324	-0.017
Particle density	-0.264	0.110	0.079	-0.080	0.269	-0.147
WHC	**0.301**	0.178	0.015	0.023	0.308	0.076
Soil moisture	0.251	0.112	-0.121	-0.008	0.310	0.117
Mean weight diameter	0.192	0.356	0.056	-0.378	-0.279	0.047
% Water stable aggregates	0.149	0.406	0.112	-0.373	-0.201	0.112
% Clay	0.010	0.225	0.331	0.005	0.065	0.401
% Silt	0.027	0.394	-0.125	**0.545**	-0.142	-0.221
% Sand	-0.038	**-0.497**	0.043	-0.449	0.102	0.053

In the first PC, organic carbon. available sulphur, bulk density and WHC had the highest loading factors but, due to the existence of high correlation, only organic carbon was retained. Second PC had per cent sand as the highest loaded factor. Available Ca, per cent silt and available P were retained from third, fourth and fifth PC respectively, Sixth PC had available N and available K as highest loaded factors and both were retained since they were not correlated. The final minimum data set consisted of seven attributes which is represented in Table 17.

Table17. Minimum data set (MDS)

PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
% OC	% Sand	Available Ca	% Silt	Available P	Available N
					Available K

4.3.2. Formulation of soil quality index (SQI)

4.3.2.1. Scoring of the parameters

Appropriate weights and scores are assigned for each parameter in the minimum data set in order to evaluate the soil quality index (Table 18) (Larson and Pierce,1994). The method suggested by Kundu *et al.* (2017) was used for scoring the parameters.

Table 18. Scoring of the parameters

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Texture (sand %)(silt %)	5 each	Loam	Clay loam/ Sandy loam	Sand/Clay	Grit
OC	10	>1	1-0.75	0.75-0.5	<0.5
Available N	25	>560	560-420	420-280	<280
Available P	20	>25	15-25	15-10	<10
Available K	20	>300	300-250	250-150	<150
Available Ca	15	>300	300-250	250-150	<150

4.3.2.2. Soil quality index (SQI)

Mean values for SQI and RSQI found during the study revealed that most of the soils to be in medium soil quality class. The RSQI ranged from 48.8 at Velloor to 87.5 at Neendoor. The highest value for RSQI was obtained at Neendoor panchayat with a mean value of 77.2 and lowest mean value as 55.6 at Vazhapally panchayat (Table 19).

4.4. NUTRIENT INDEX (NI)

The nutrient index values calculated for organic carbon showed that the fertility status of the area was medium to high. High fertility status was observed in all the 18 panchayats except Kumarakom, Velloor, Paippad and T.V. Puram. The lowest NI of 2 was interpreted at Kumarakom and Velloor panchayat. The nutrient index of nitrogen revealed a low nutrient status in all panchayats except Kaduthuruthy and Kallara. But nutrient index value for phosphorous and potassium was medium to high in majority of the panchayats. A low nutrient index value of potassium was observed at Chempu, Vazhapally and Velloor panchayats. The nutrient indices are provided in Table 20.

Table 19. SQI and RSQI of post-flood soils of AEU 4 in Kottayam district

Panchayat	SQI		RSQI	
	Mean±SD	Range	Mean±SD	Range
Kumarakom	273±34.2	235-305	68.4±8.70	58.8-76.3
Thiruvarp	275±56.6	235-315	68.8±14.1	58.8-78.8
Neendoor	308±32.0	275-350	77.2±8.00	68.8-87.5
Arpookara	267±28.4	235-300	66.9±7.11	58.8-75.0
Aymanam	253±45.4	200-315	63.3±11.3	50.0-78.8
Kaduthuruthy	285±33.4	240-315	71.3±8.35	60.0-78.8
Thalayolaparambu	279±21.3	255-315	69.8±5.48	63.8-78.8
Mulakkulam	283±27.5	255-315	70.6±6.88	63.8-78.8
Kallara	267±23.1	240-280	66.7±5.77	60.0-70.0
Velloor	247±41.1	195-285	61.9±10.3	48.8-71.3
Vazhapally	223±3.54	220-225	55.6±0.88	55.0-56.3
Paippad	284±36.1	250-315	71.0±9.04	62.5-78.8
Thrikodithanam	275±39.2	225-315	68.8±9.79	56.3-78.8
TV Puram	255±30.3	215-295	63.8±7.58	53.8-73.8
Udayanapuram	272±37.9	225-315	67.9±9.48	56.3-78.8
Vechoor	275±13.5	255-285	68.8±3.38	63.8-71.3
Thalayazham	263±31.7	225-300	65.8±7.94	56.3-75.0
Chempu	261±34.4	215-295	65.3±8.6	53.8-73.8
AEU 4	270±33.4	195-350	67.43±8.31	48.8-87.5

Table 20. Nutrient index (NI) of organic carbon and primary nutrients in post-flood soils of AEU 4 of Kottayam district

Panchayat	Organic carbon		Available N		Available P		Available K	
	NI (OC)	Status	NI(N)	Status	NI (P)	Status	NI (K)	Status
Kumarakom	2.00	Medium	1.50	Low	2.25	Medium	2.25	Medium
Thiruvarp	3.00	High	1.00	Low	2.50	High	2.50	High
Neendoor	2.50	High	1.25	Low	2.50	High	2.50	High
Arpookara	3.00	High	1.50	Low	1.75	Medium	2.50	High
Aymanam	2.80	High	1.00	Low	2.00	Medium	2.00	Medium
Kaduthuruthy	3.00	High	1.75	Medium	1.50	Low	2.75	High
Thalayolaparambu	2.60	High	1.00	Low	2.80	High	2.20	Medium
Mulakkulam	2.75	High	1.00	Low	2.75	High	2.25	Medium
Kallara	3.00	High	2.00	Medium	1.00	Low	2.67	High
Velloor	2.00	Medium	1.00	Low	2.50	High	1.50	Low
Vazhapally	2.50	High	1.50	Low	1.50	Low	1.50	Low
Paippad	2.25	Medium	1.00	Low	3.00	High	2.00	Medium
Thrikodithanam	2.50	High	1.00	Low	3.00	High	2.00	Medium
TV Puram	2.17	Medium	1.00	Low	2.67	High	1.67	Medium
Udayanapuram	2.50	High	1.16	Low	2.50	High	2.17	Medium
Vechoor	3.00	High	1.50	Low	1.75	Medium	2.75	High
Thalayazham	2.40	High	1.40	Low	2.60	high	1.80	Medium
Chempu	2.40	High	1.0	Low	2.80	High	1.60	Low

4.5. LAND QUALITY INDEX (LQI)

The value for land quality index varied from 0.80 to 19.3 kg m^{-2} at various parts of the AEU and the mean value was recorded as 4.17 kg m^{-2}. Land quality index calculated was maximum at Kallara panchayat as 10.0 kg m^{-2} and minimum at Velloor as 1.95 kg m^{-2}. Kallara and Velloor panchayat recorded respectively the highest and lowest soil organic carbon stock also (Table 21)

Table 21. Land quality index of post-flood soils of AEU 4 in Kottayam district

Panchayat	SOCS (Mg ha $^{-1}$)		LQI (kg m^{-2})	
	Mean±SD	Range	Mean±SD	Range
Kumarakom	22.8±16.4	8.02-18.6	2.28±1.64	0.80-1.86
Thiruvarp	34.9±10.9	27.2-42.7	3.49±1.09	2.72-4.27
Neendoor	30.3±4.92	23.0-33.8	3.03±0.49	2.30-3.38
Arpookara	55.1±22.3	32.2-84.8	5.51±2.26	3.22-8.48
Aymanam	36.2±14.6	23.7-60.4	3.62±1.46	2.37-6.04
Kaduthuruthy	67.4±38.8	41.9-125	6.74±3.88	4.19-12.5
Thalayolaparambu	33.8±14.6	19.9-55.7	3.38±1.46	1.99-5.57
Mulakkulam	28.6±9.21	21.4-41.4	2.86±0.92	2.14-4.14
Kallara	100±28.3	70.8-127	10.0±2.83	7.08-12.7
Velloor	19.5±2.70	16.9-22.0	1.95±0.27	1.69-2.20
Vazhapally	55.3±50.6	19.5-91.1	5.53±5.06	1.95-9.11
Paippad	29.7±11.6	16.7-44.6	2.97±1.16	1.67-4.46
Thrikodithanam	30.8±14.5	17.8-47.2	3.08±1.45	1.78-4.72
T.V.Puram	25.2±9.76	18.8-44.3	2.52±0.98	1.88-4.43
Udayanapuram	30.5±12.5	17.8-49.2	3.05±1.25	1.78-4.92
Vechoor	90.1±52.0	53.2-166	9.01±5.20	5.32-16.7
Thalayazham	63.0±73.8	11.0-192	6.30±7.38	1.10-19.3
Chempu	29.6±11.7	19.8-48.5	2.96±1.17	1.98-4.85
AEU 4	41.7±33.1	8.00-192	4.17±3.31	0.80-19.3

4.6. CORRELATION ANALYSIS

Correlations were worked out between,

(i) Various physical parameter

(ii) Various chemical and biological parameters

(iii) Various physical, chemical and biological parameters

4.6.1. Correlation among different physical parameters

Correlation studies on physical parameters revealed that bulk density showed a significant negative correlation with porosity (-0.803**), soil moisture (-0.608**) and WHC (-0.909**). A significant positive correlation was observed between WHC and porosity (0.708**), MWD (0.354**) and per cent water stable aggregates (0.348**), WHC and soil moisture (0.582**), MWD and percent water stable aggregates (WSA) (0.844**) (Table 22)

Table 22. Correlation coefficients worked out among various physical parameters

	BD	**PD**	**Porosity**	**WHC**	**moisture**	**MWD**	**% WSA**	**Clay**	**Silt**	**Sand**
BD	1.000									
PD	0.379**	1.000								
Porosity	-0.803**	0.241*	1.000							
WHC	-0.909**	-0.389**	0.708**	1.000						
Moisture	-0.608**	-0.411**	0.390**	0.582**	1.000					
MWD	-0.433**	-0.197	0.354**	0.410**	0.365**	1.000				
%WSA	-0.379**	-0.112	0.348**	0.394**	0.310**	0.844**	1.000			
Clay	-0.080	-0.050	0.054	0.151	0.064	0.145	0.181	1.000		
Silt	-0.072	0.065	0.131	0.145	0.228*	0.128	0.133	-0.032	1.000	
Sand	0.138	0.027	-0.136	-0.275*	-0.240*	-0.228*	-0.272*	-0.274*	-0.811**	1.000

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

4.6.2. Correlation among different chemical parameters

Among various chemical parameters, pH showed a significant negative correlation with organic carbon (-0.635**), available sulphur (-0.661**), available magnesium (-0.438**) and boron (-0.361**) while a significant positive correlation was observed in terms of organic carbon with available sulphur (0.796**), acid phosphatase activity (0.627**), EC with available potassium (0.235**), available magnesium (0.803**), available sulphur (0.602**) (Table 23)

Table 23. Correlation coefficients worked out among various chemical and biological parameters

	pH	EC	OC	N	P	K	Ca	Mg	S	B	Phosphatase
pH	1.000										
EC	-0.428**	1.000									
OC	-0.635**	0.555**	1.000								
N	-0.111	0.472**	0.382**	1.000							
P	0.245*	-0.195	-0.290*	-0.238*	1.000						
K	-0.110	0.235*	0.377**	0.167	0.037	1.000					
Ca	0.351**	0.193	0.069	0.249*	0.145	0.228*	1.000				
Mg	-0.438**	0.505**	0.803**	0.304**	-0.325**	0.479**	0.209	1.000			
S	-0.661**	0.602**	0.796**	0.363**	-0.278*	0.265*	0.137	0.747**	1.000		
B	-0.361**	0.570**	0.531**	0.343**	-0.159	0.116	0.127	0.404**	0.554**	1.000	
Acid phosphatase	-0.467**	0.453**	0.627**	0.336**	-0.154	0.292*	0.041	0.393**	0.484**	0.542**	1.00

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

4.6.3. Correlation among different physical, chemical and biological parameters

Bulk density with organic carbon (-0.615**), Particle density with organic carbon (-0.518**) showed a significant negative correlation. Organic carbon showed a significant positive correlation with porosity (0.614**), WHC (0.614**), soil moisture (0.465**) and MWD (0.228**) (Table 24)

Table 24. Correlation coefficients worked out among various physical, chemical and biological parameters

Parameter	BD	PD	Porosity	WHC	Soil moisture	MWD	WSA	Clay	Silt	Sand
pH	0.524**	0.510**	-0.219	-0.450**	-0.429**	-0.154	-0.043	0.126	-0.046	0.025
EC	-0.459**	-0.273*	0.307**	0.456**	0.192	0.205	0.164	-0.051	-0.000	-0.000
OC	-0.615**	-0.518**	0.315**	0.614**	0.465**	0.228*	0.171	-0.007	0.011	0.023
N	-0.438**	-0.117	0.366**	0.356**	0.193	0.215	0.167	0.012	-0.055	0.058
P	0.198	0.301**	-0.021	-0.190	-0.165	-0.295*	-0.183	0.023	0.006	0.039
K	-0.113	-0.232*	-0.027	0.153	0.095	0.018	0.074	0.013	-0.061	0.055
Ca	-0.069	0.114	0.140	0.091	-0.015	-0.009	-0.023	0.214	0.014	-0.011
Mg	-0.475**	-0.446**	0.222	0.426**	0.421**	0.190	0.079	-0.022	-0.051	0.102
S	-0.533**	-0.479**	0.249*	0.471**	0.433**	0.250*	0.080	-0.059	-0.007	0.072
B	-0.559**	-0.320**	0.397**	0.545**	0.421**	0.444**	0.338**	-0.018	0.016	-0.045
Acid Phosphatase	-0.556**	-0.313**	0.413**	0.615**	0.543**	0.393**	0.310**	-0.008	0.011	-0.033

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

Discussions

5. DISCUSSION

The present investigation entitled "Assessment of soil quality in the post-flood scenario of AEU 4 in Kottayam district" was carried out to analyse the soil quality in the flood affected areas of AEU 4 in Kottayam district. The analysed parameters were then used to formulate MDS and assess SQI. The results obtained during the course of investigation are discussed in this chapter with supporting literatures.

5.1. CHARACTERIZATION OF SOIL

Results obtained from the analysis of various physical, chemical and biological attributes are discussed below.

5.1.1. Physical attributes

5.1.1.1. Bulk density

Bulk density generally showed a low value in the area**.** A value less than 1.2 Mg m^{-3} was recorded for 50.7 per cent of soil sample, 28 percent recorded a value between 1.2 to 1.4 Mg m^{-3} and 21.3 per cent recorded a value between 1.4 to 1.6 Mg m^{-3} (Figure 4) The lower bulk density reported can be due the increased organic matter in the soil.

Similar values in which bulk density ranged from 0.67 to 1.35 Mg m^{-3} was reported in North Kuttanad (Thampatti and Jose, 2000). The present study showed a significant negative correlation between organic carbon and bulk density (-0.615^{**}). Similar correlation was observed by Chaudhari *et al.* (2013)

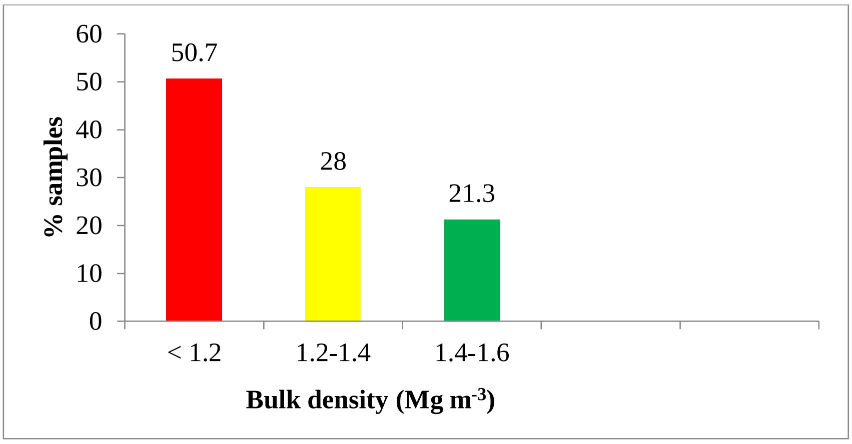


Figure 4. Frequency distribution of bulk density in post-flood soils of AEU 4 in Kottayam district

5.1.1.2. Particle density

A particle density value of less than 2.2 Mg m^{-3} was observed in about 73.3 per cent samples whereas 16 per cent samples recorded values between 2.2 to 2.4 Mg m^{-3} and 10.7 per cent of analysed samples represented a value greater than 2.4 Mg m^{-3} (Figure 5). Presence of higher quantities of organic carbon could be the reason for the significantly lesser values of particle density, as the value is characteristic of the mineral or organic particles. A significant negative correlation was observed between particle density and organic carbon (-0.518^{**})

Thampatti and Jose (2000) recorded absolute gravity of 1.60 to 2.51 Mg m^{-3} in soils of north Kuttanad. A strong negative correlation between total soil organic carbon and particle density was reported by Li *et al,* (2007) where particle density was found to increase as organic carbon depleted.

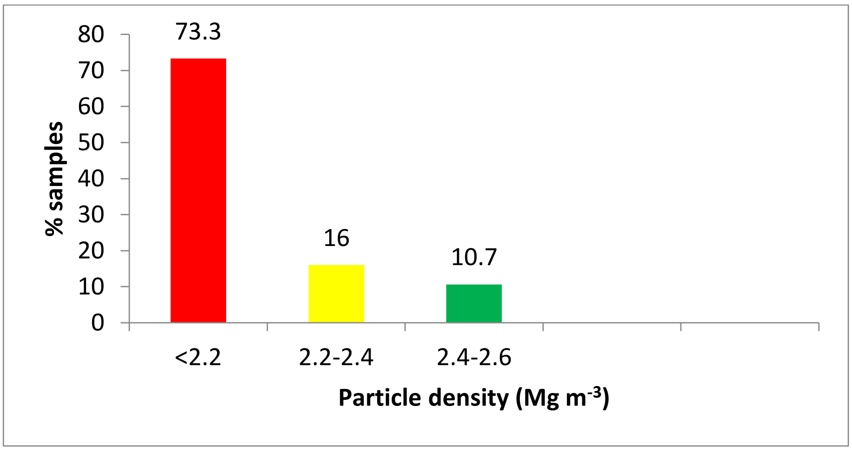


Figure 5. Frequency distribution of particle density in post-flood soils of AEU 4 in Kottayam district

5.1.1.3. Porosity

Less than 30 per cent porosity was recorded in 12 per cent of samples. Maximum number of samples (65.3 per cent) had a porosity value from 30 to 40 per cent, 21 per cent samples had 50 to 70 per cent of porosity and 1.33 per cent samples recorded value greater than 70 per cent (Figure 6)

Higher organic matter present is mainly responsible for the higher porosity in the area. Porosity showed significant negative correlation with bulk density (-0.803**) and organic carbon showed significant positive correlation with porosity (0.315**).

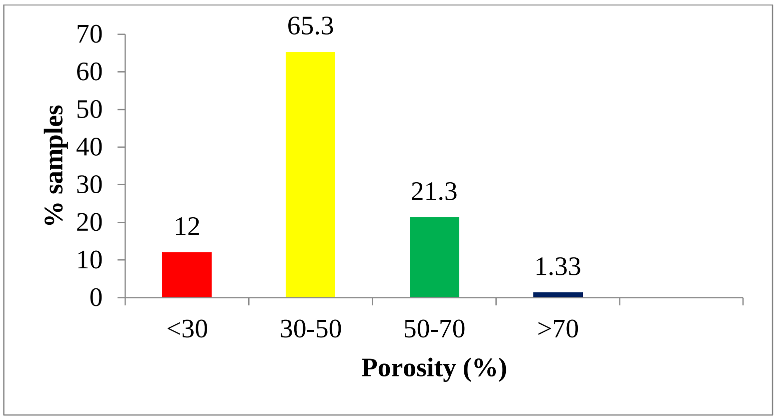


Figure 6. Frequency distribution of porosity in post-flood soils of AEU 4 in Kottayam district

5.1.1.4. Soil texture

Textural class of the samples were found to be sandy clay loam (60 per cent), sandy loam (22.7 per cent) clay loam (8.0 per cent), loam (4.0 per cent), silt loam (1.33 per cent) and sandy clay (4 per cent) (Figure 7) There was not much variation in the texture of soils after flood. Spatial distribution of soil texture in the area is presented in figure 8.

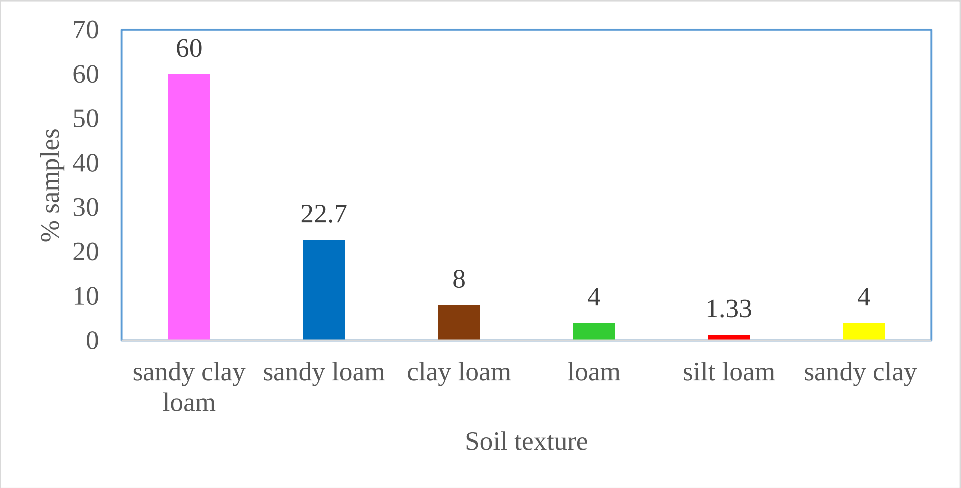


Figure 7. Frequency distribution of soil textural class in post-flood soils of AEU 4 in Kottayam district

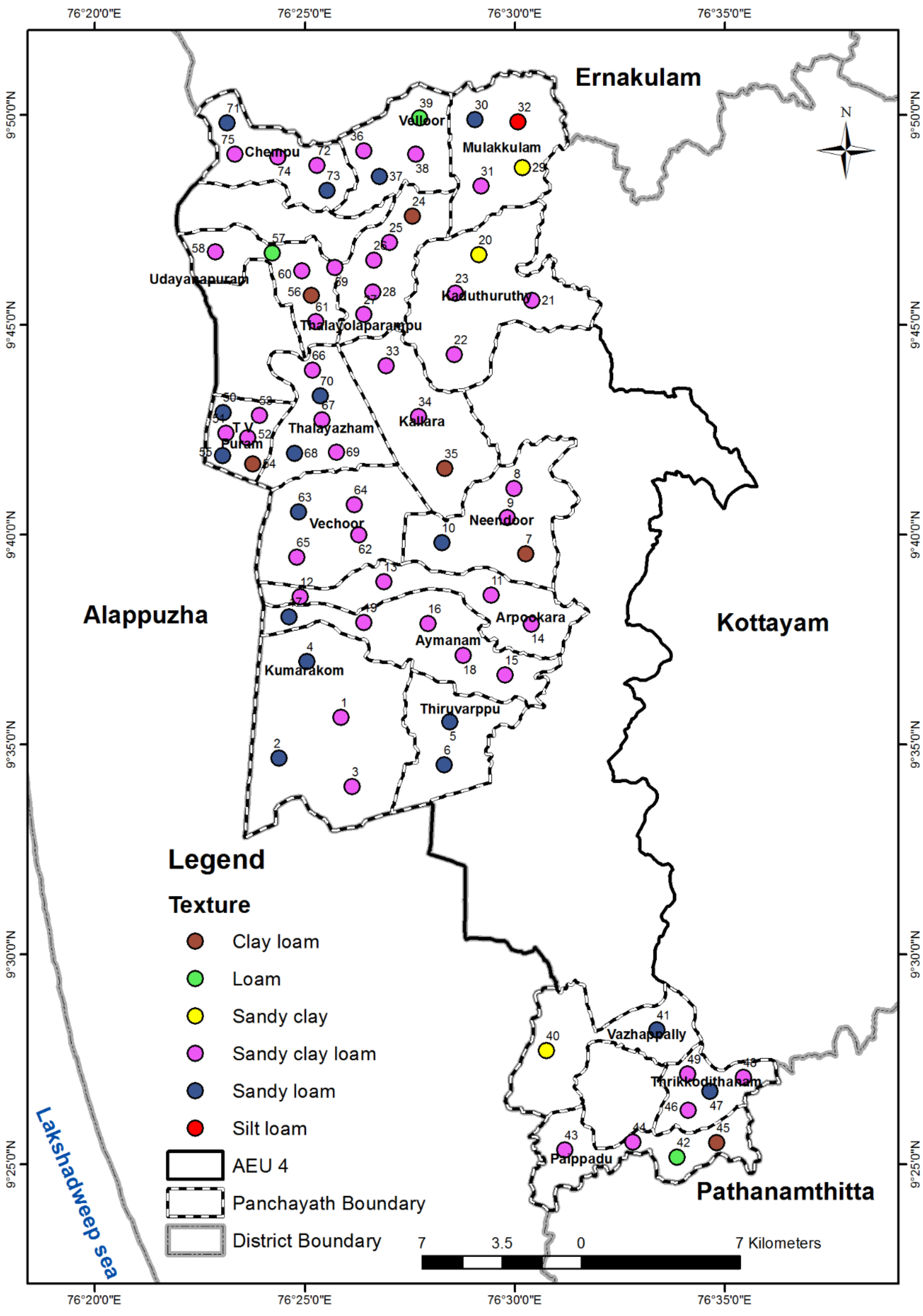


Figure 8. Spatial distribution of soil texture in post-flood soils of AEU 4 in Kottayam district

5.1.1.6. Maximum water holding capacity

Among the samples analysed, 9.33 per cent samples recorded less than 30 per cent WHC, 65.3 per cent recorded WHC 30 to 50 per cent and 25.3 per cent samples showed a WHC greater than 50 per cent (Figure 9).

Increased water holding capacity is attributed to the increased porosity. The organic matter content too has a great potential to hold water. Water holding capacity was having significant negative correlation with per cent sand (-0.275*) and positive correlation with soil moisture (0.582**), MWD (0.410**) and % water stable aggregates (0.394**)

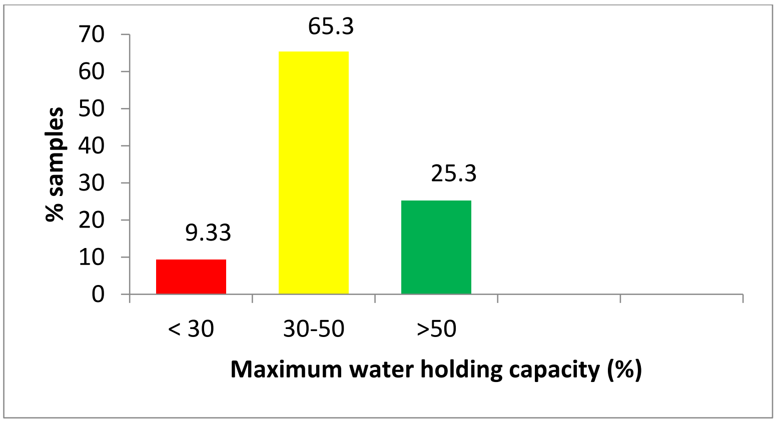


Figure 9. Frequency distribution of water holding capacity in post-flood soils of AEU 4 in Kottayam district

5.1.1.7. Soil moisture

From the samples analysed, 26.7 per cent had a value less than 10 per cent as moisture content. Soil moisture content of 25.3 per cent samples varied between 10 to 15 percent, 17.3 per cent samples between 15 to 25 per cent and 37 per cent samples recorded more than 25 per cent soil moisture content (Figure 10)

The higher soil moisture is also attributed due to the increased porosity of the soil. Soil moisture content was also significantly correlated with organic carbon.

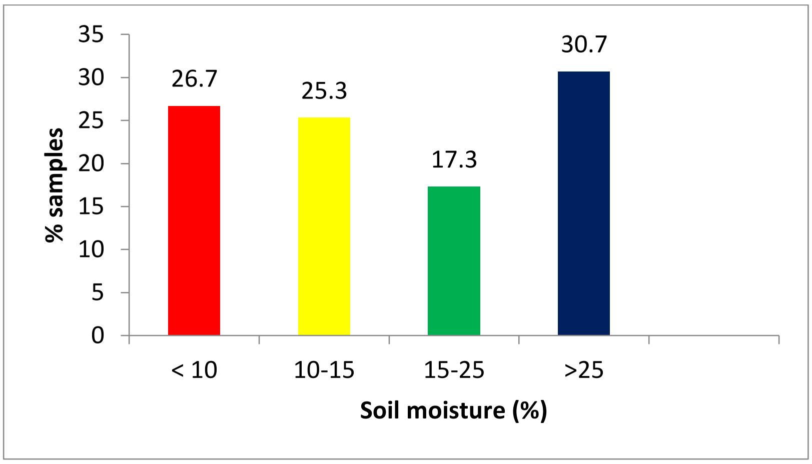


Figure 10. Frequency distribution of soil moisture in post-flood soils of AEU 4 in Kottayam district

5.1.1.8. Aggregate analysis

Mean weight diameter and per cent water stable aggregates which signifies the aggregate stability was estimated for the samples. The MWD of 28 per cent samples were found to be less than 1 mm, 38.7 per cent samples obtained MWD value between 1.0 to 1.5 mm, 10.7 per cent samples recorded values between 1.5 to 2.0 mm and 22.7 per cent recorded MWD greater than 2.0 mm (Figure 11)

Percentage water stable aggregates values were also obtained and 78.7 per cent samples were reported to have WSA more than 50 per cent, 16 per cent samples recorded 40 to 50 per cent and 5.33 per cent samples recorded values ranging from 30 to 40 per cent WSA (Figure 12)

Soils with high organic matter will be highly aggregated, the presence of higher organic matter was responsible for better percentage water stable aggregates. MWD was positively correlated with organic carbon (0.228^{*}) and percentage water stable aggregates was negatively correlated with per cent sand (-0.272^{*}). Toogood and Lynch (1959) observed an increase in MWD in manure treated plots and opined that low organic matter and clay content rendered the soil less aggregated. Similar results with increase in MWD was reported on addition of amendments like urban compost and gypsum (Emami and Astaraei, 2012)

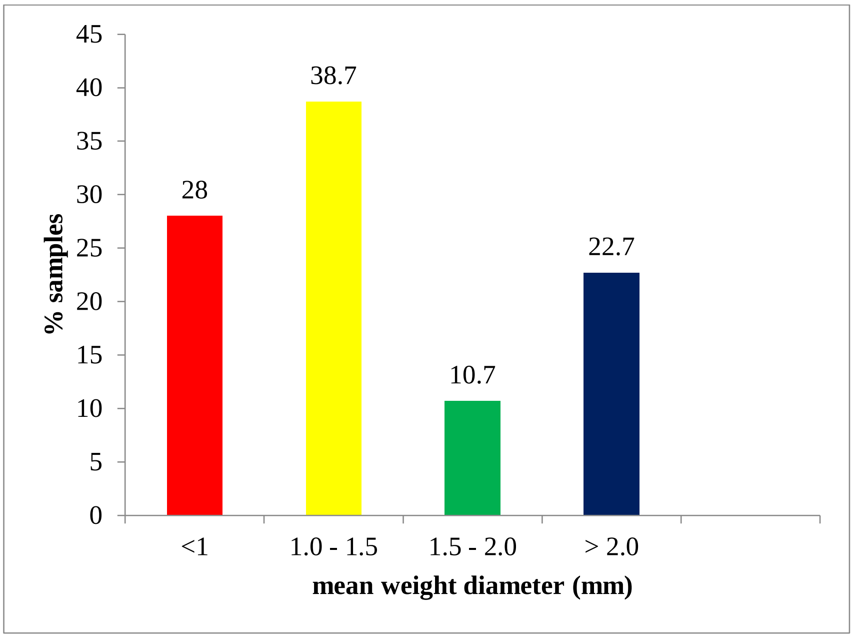


Figure 11. Frequency distribution of mean weight diameter in post-flood soils of AEU 4 in Kottayam district

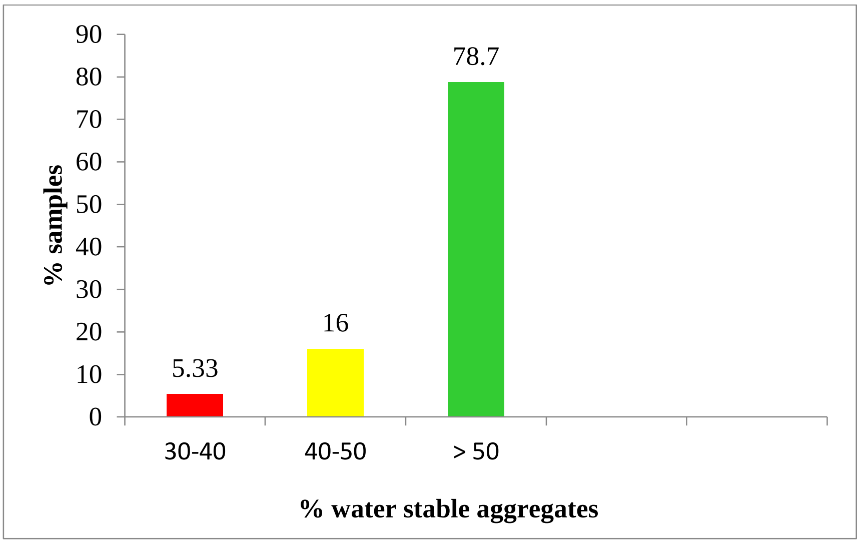


Figure 12. Frequency distribution of percentage water stable aggregates in post-flood soils of AEU 4 in Kottayam district

5.1.2. Chemical attributes

5.1.2.1. pH

More than 90 per cent of the samples reported a pH in acidic range which included 6.67 per cent as ultra-acidic, 17.33 per cent as extremely acidic, 20 per cent as very strongly acidic, 14.7 per cent as strongly acidic (Figure 13). Similar results have been obtained by Beena (2005) where pH of surface soil samples from Kuttanad ranged from 2.4 - 5.6. The samples were collected from the flood affected areas and the flood water might have influenced the pH in the present study. The major constraint for crop production in this area is extreme acidity. Iyer (1989) reported the presence of pyrites in low lying areas of Kerala. The production of sulphuric acid on oxidation of sulphur compounds or pyrites have increased acidity. This was confirmed by the fact that there was a significant negative correlation between pH and available sulphur (-0.661^{**}).

The organic acids released from decomposition of organic compounds are also responsible for the acidity. pH and organic carbon also had significant negative correlation (0.635^{**}).

On comparison to the pre flood data percentage of samples in ultra-acidic pH range had increased by 3.11 per cent but per cent samples in extremely acidic, very strongly acidic and strongly acidic decreased in post-flood condition. (figure 14). The percentage of samples in the neutral range has also increased which can be the effect of flooding. Kabeerathumma and Patnaik (1978) reported an increase in pH of soil after flooding in acid sulphate soils of Kerala.

This pH range was highly expected as the areas are potentially acid sulphate as reported by Thampatti (1997). Nath *et al.* (2016) also confirmed the extreme acidity of Kuttanad soil (2.4 – 4.8) and stated a relation between pH and availability of nutrients. Spatial distribution of soil pH in AEU 4 of Kottayam district is presented in the figure 15.

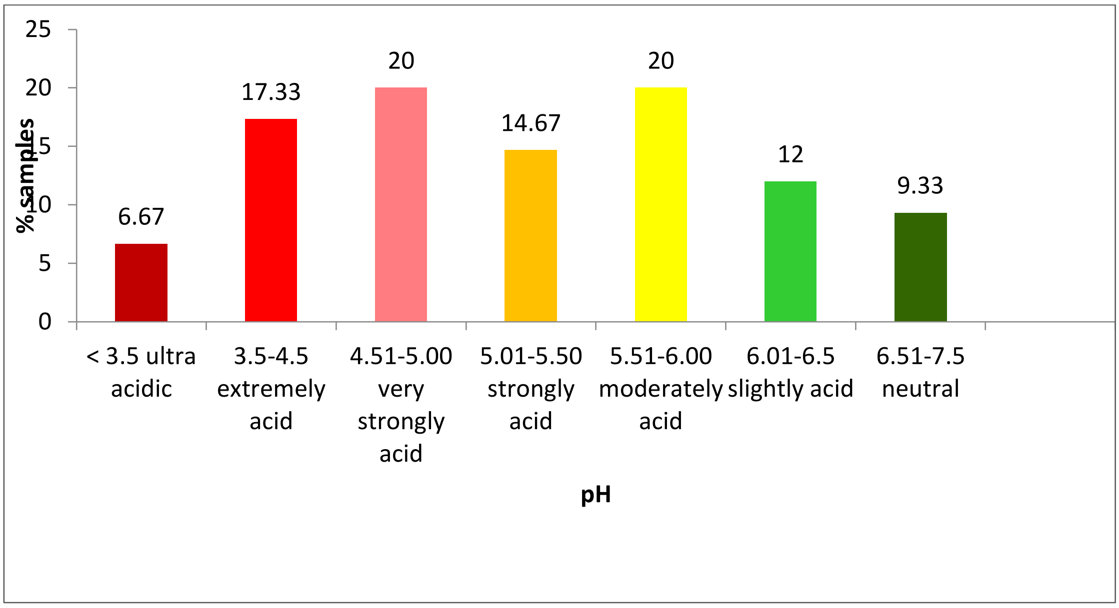
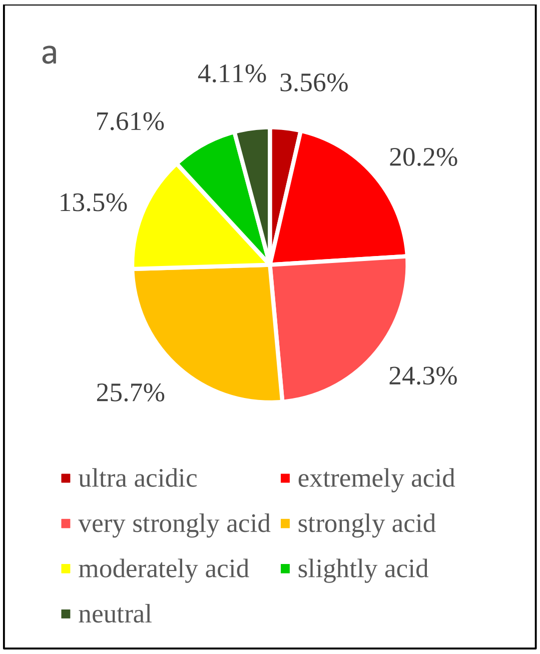


Figure 13. Frequency distribution of soil pH in post-flood soils of AEU 4 in Kottayam district



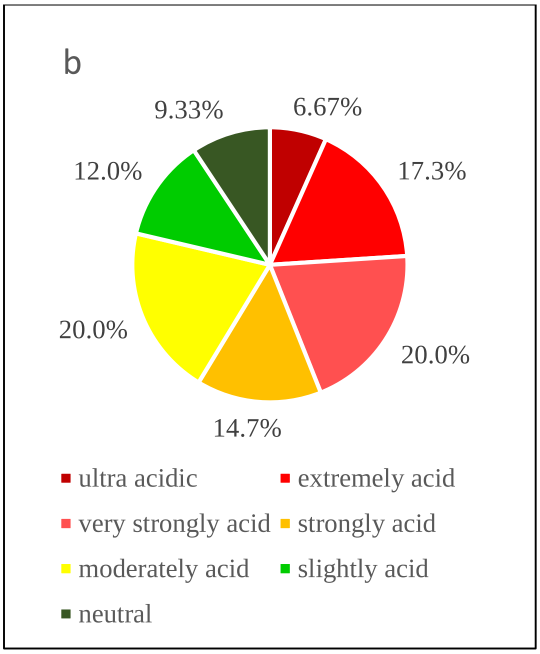


Figure 14. Comparison of frequency of pH in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

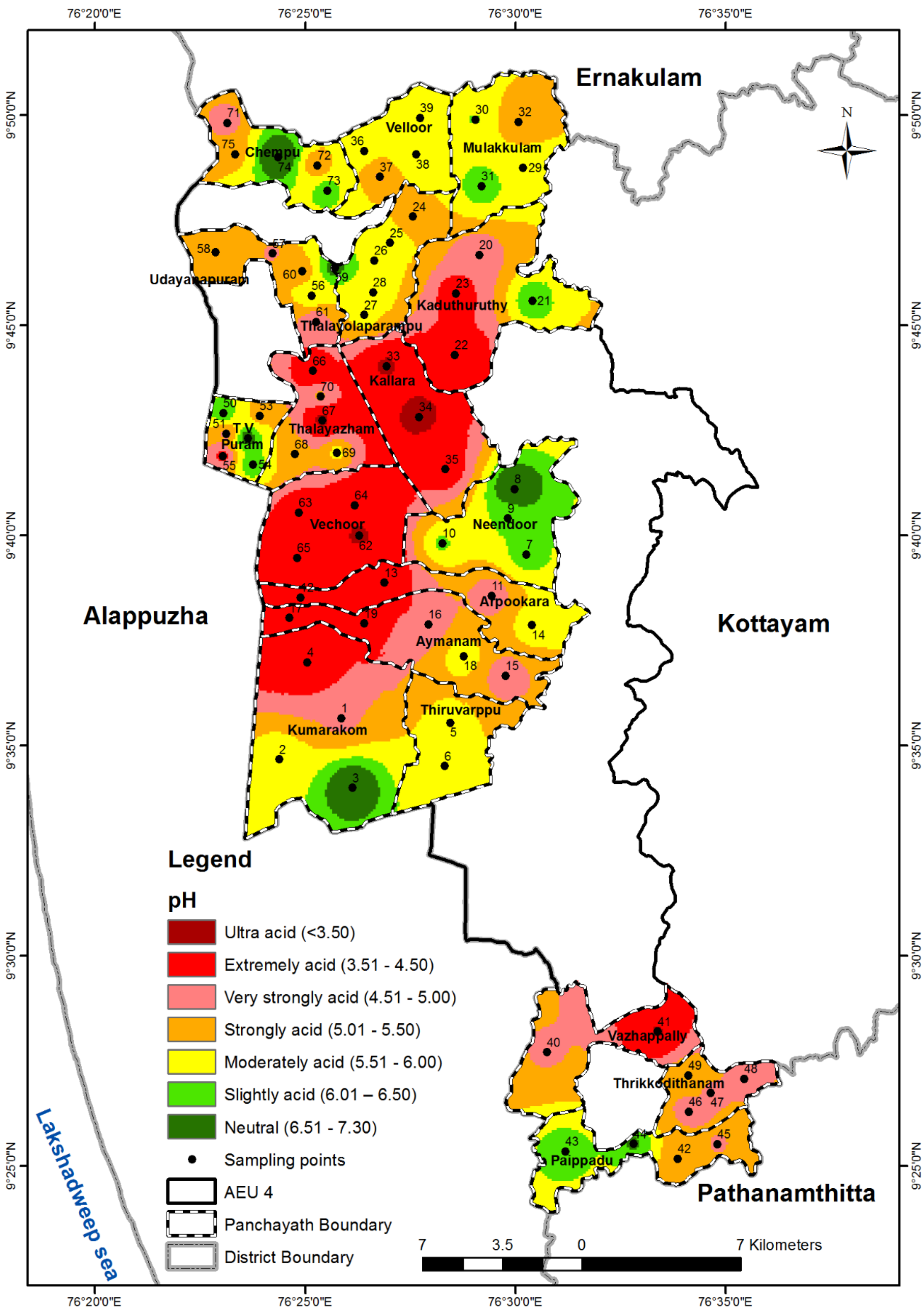


Figure 15. Spatial distribution of soil pH in post flood soils of AEU 4 of Kottayam district

5.1.2.2. Electrical conductivity (EC)

The values for EC ranged from 0.05 – 3.9 dS m^{-1} in the AEU with 89.3 percent samples falling into the category having < 1 dS m^{-1} and 5.33 percent each in 1-2 dS m^{-1} and 2-4 dS m^{-1} category (Figure 16). Beena (2005) found a variation of EC values from 0.92 – 3.49 dS m^{-1} in Kuttanad soils. The same trend in EC values was observed in an incubation study conducted by Nath *et al.* (2020) from Kallara and Vaikom series.

The higher EC values of some areas can be due to the saline water intrusion during summer months. This can be also attributed to different levels of sulphate and potassium ions present in the soil (Iyer, 1989)

Similar results were obtained by Department of soil survey and soil conservation (GOK, 2018) in the post flood analysis of Kerala where EC values recorded a mean value of 1.2 dS m^{-1} in low lands of Kottayam. It was also reported a reduction in EC values as compared to pre-flood data.

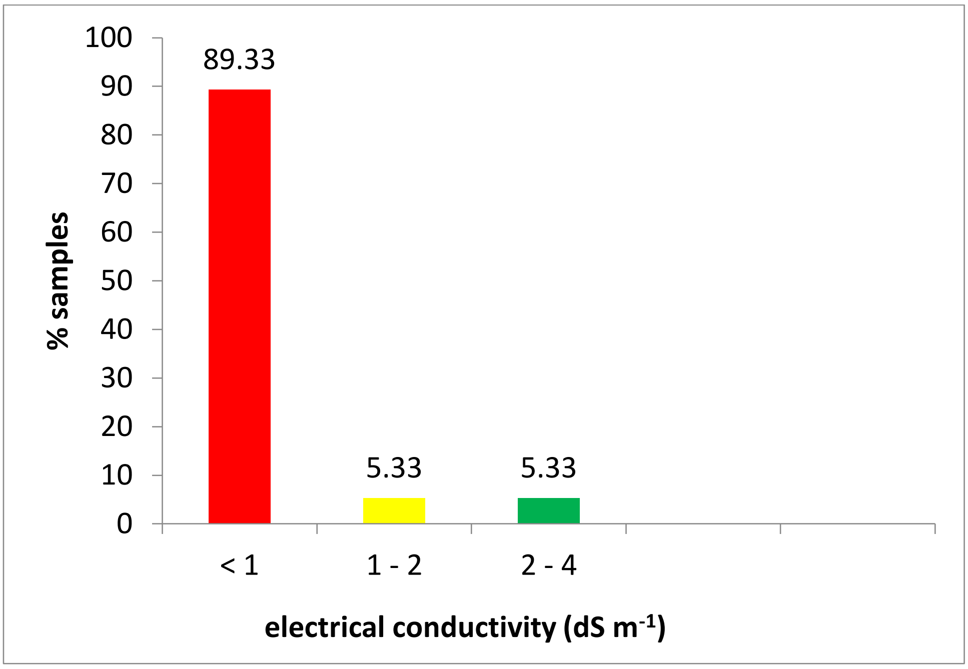


Figure 16. Frequency distribution of electrical conductivity in post-flood soils of AEU 4 of Kottayam district

5.1.2.3. Organic carbon

Organic carbon content of Kuttanad is generally reported to be high. A similar observation was obtained here also. The samples in high category which was 32.8 per cent in pre-flood condition had increased to 58.7 per cent, and 27.9 per cent in low category had reduced to 2.67 per cent. Not much change was reported in per cent samples in medium class (KSPB, 2013) (Figure 18).

From the comparison, it is clear that an increase in organic carbon content was observed in majority of the places. The increased organic carbon can be due to the deposition of organic materials by the flood water. Similar observation (4.34 per cent on average) was obtained by GOK (2018) on analysing the soil health status of post-flood soils of Kerala.

Abundance of partially decomposed fossil woods and roots were observed at different stage of decomposition in acid sulphate soils of Kuttanad (Iyer, 1989). The surface soil samples of Kuttanad recorded 4.72 to 9.25 per cent soil organic carbon in an investigation by Beena (2005). Similar findings were reported by Kannan *et al*. (2014) where the OC content varied from 2.79 to 7.70 per cent. Increased organic carbon can improve various physical, chemical and biological attributes and can be beneficial for crop growth. In the present study it has influenced many parameters like bulk density, particle density, WHC, acid phosphatase activity etc. Spatial distribution of organic carbon content in the post flood soils of AEU 4 is presented in figure 19.

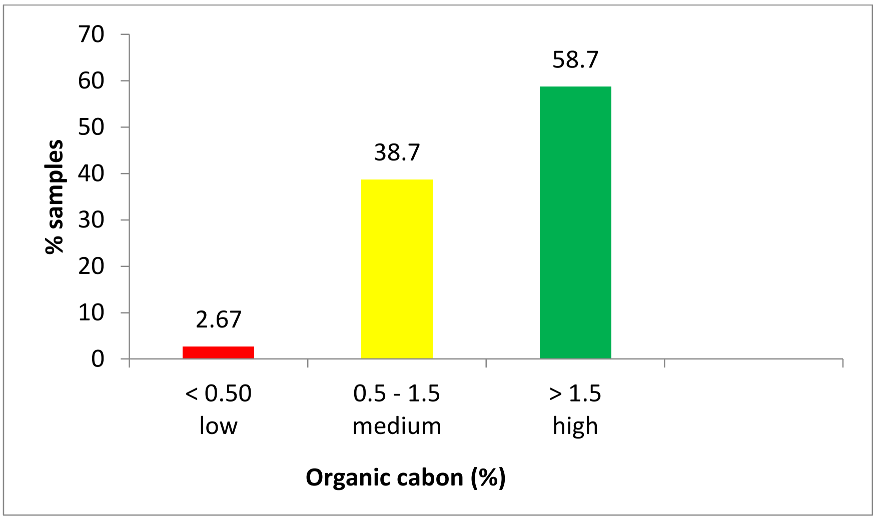


Figure 17. Frequency distribution of organic carbon in post flood soils of AEU 4 of Kottayam district.

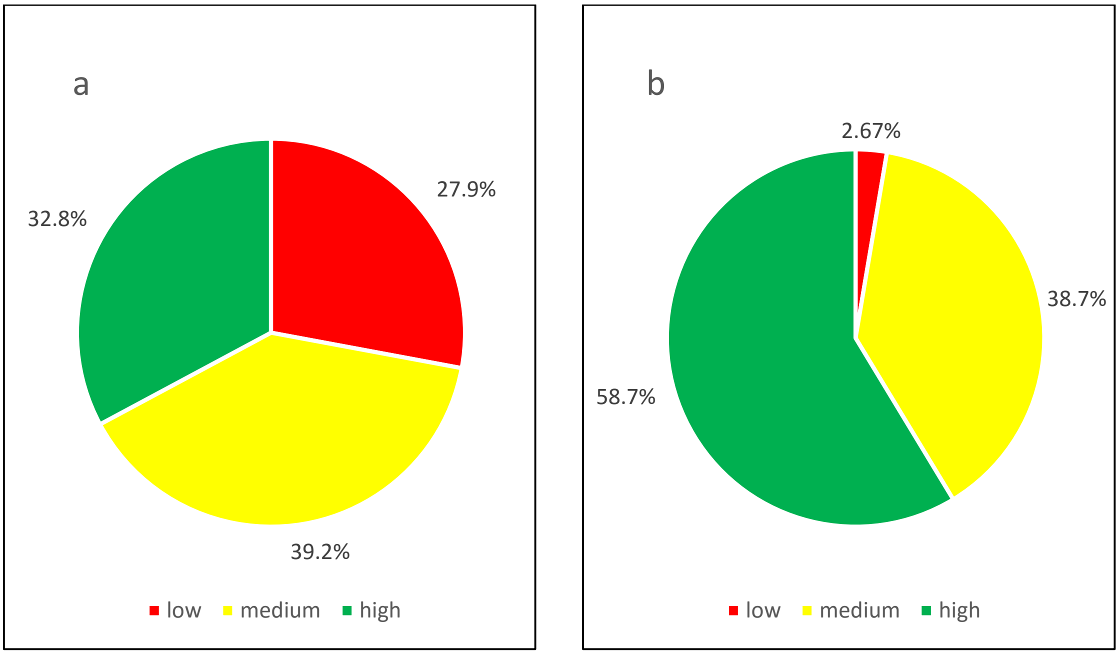


Figure 18. Comparison of frequency of organic carbon in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

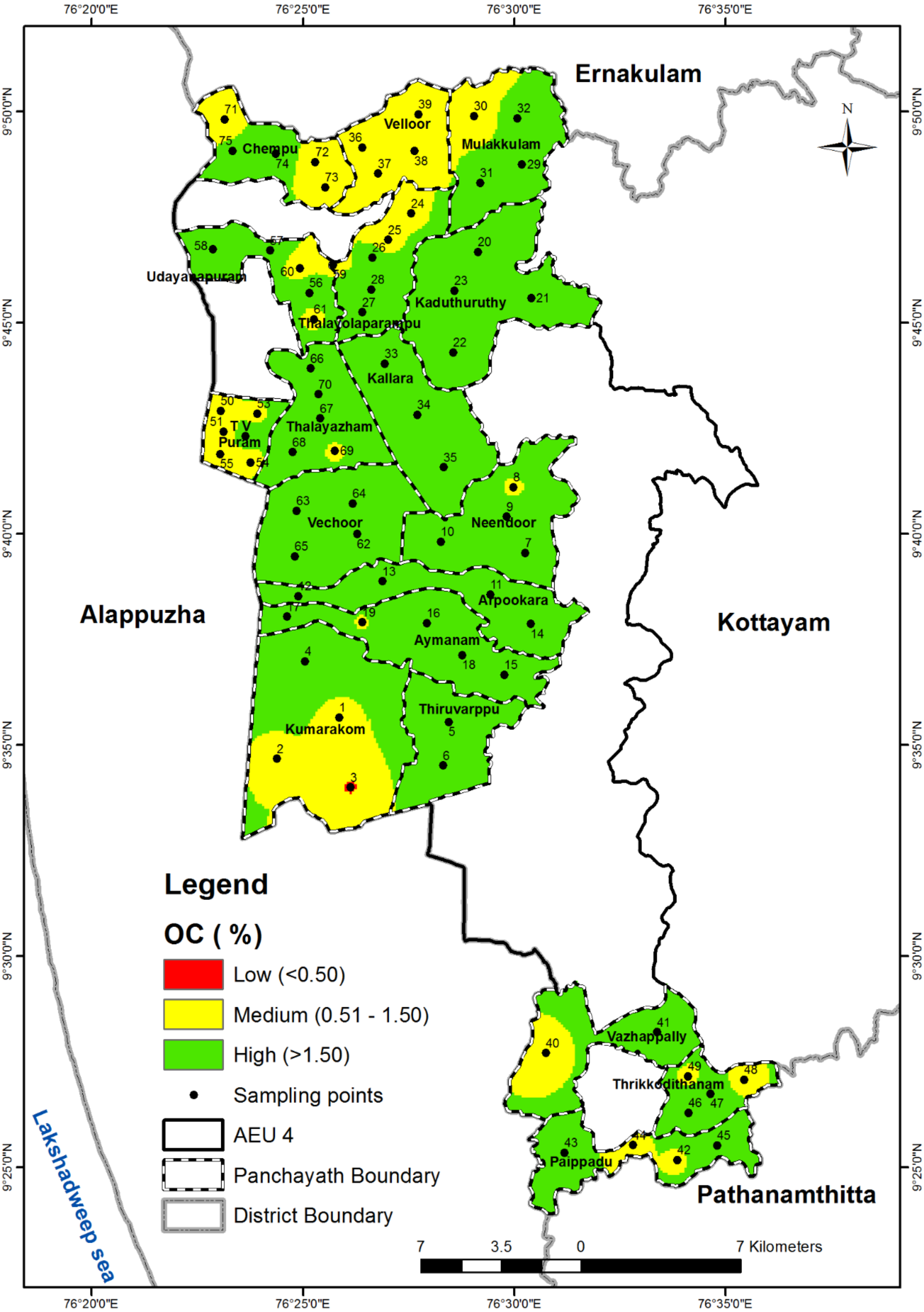


Figure 19. Spatial distribution of organic carbon in post flood soils of AEU 4 of Kottayam district

5.1.2.4. Available nitrogen

Available nitrogen status was generally low in the area. Study reported 78.7 per cent samples as low, 18.7 per cent as medium and 2.67 per cent as high in available nitrogen (Figure 20)

Usually, soil recommendations for nitrogen is based on carbon content due to the fact that C: N ratio stabilizes at 10:1. The presence of high organic carbon per cent and low available nitrogen present can be due to the difference in various forms of organic carbon present in total and active or labile pools and also due to the slow decomposition of organic matter on submergence. The nitrogen deficiency might be aggravated by leaching losses of nitrogen.

John (2019) pointed out that hot water extractible carbon (HWEC) can be used for determining available or mineralizable nitrogen since they found a significant correlation between hot water extractible carbon with total nitrogen and available nitrogen.

Spatial distribution of available nitrogen in post flood soils is presented in figure 21.

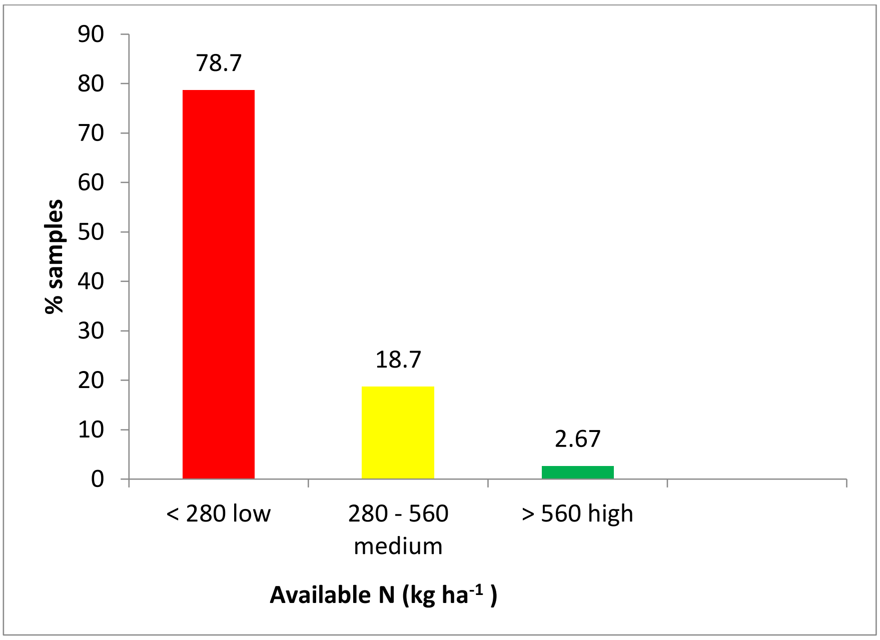


Figure 20. Frequency distribution of available nitrogen in post flood soils of AEU 4 of Kottayam district

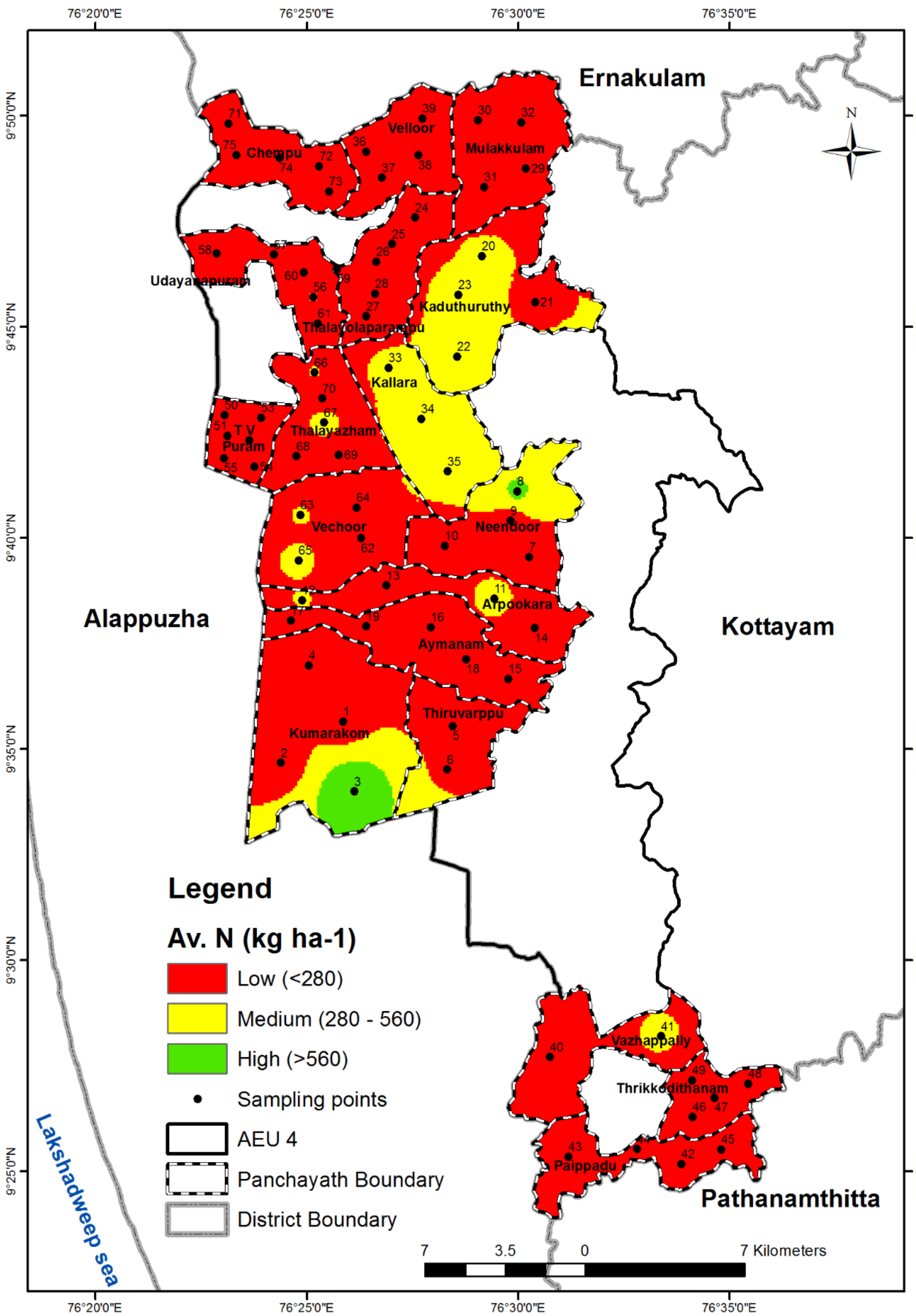


Figure 21. Spatial distribution of available nitrogen in post flood soils of AEU 4 of Kottayam district

5.1.2.5. Available phosphorus

Availability of phosphorus was high in 54.7 per cent samples, medium in 22.7 percent and low in 22.6 samples (Figure 22) whereas pre flood data signified 12.7 per cent as low, 10.9 per cent as medium and 76.4 per cent as high in phosphorus content (KSPB, 2013) (figure 23)

Kerala soils in general and Kuttanad soil in particular were having a low phosphorus status in 90s. This was mainly due to the fixation of phosphorous in Fe^{2+} and Al^{3+} ions forming complexes rendering them unavailable for plant uptake. For this reason, high application of phosphorus fertilizers was recommended (Kuruvila and Patnaik, 1994; Beena, 2005). Practice of phosphorus fertilization followed by the farmers might have influenced the effect of increased phosphorus status.

Rajasekharan (2013) conducted a study and reported that among the samples selected 61 per cent was high to very high in availability of phosphorus. He concluded it to be due to over fertilization and addition of high organic manures that is being practiced in the area. Moreover, the lowering of acidity as a result of flooding might have influenced in the release of phosphorus from fixed forms.

Koruth (2007) reported that varying doses of fertilizer phosphorus did not influence the yield (grain and straw) significantly and phosphorus use efficiency was higher at lower level of phosphorus (45 kg ha^{-1}) in the rice crop of Kuttanad.

Spatial distribution of available phosphorus in post flood soils of study area is depicted in figure 24.

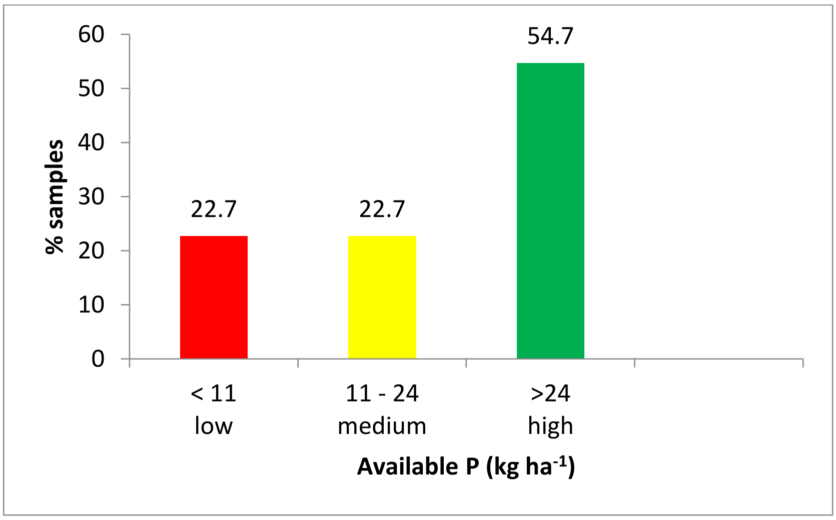


Figure 22. Frequency distribution of available phosphorous in post flood soils of AEU 4 of Kottayam district

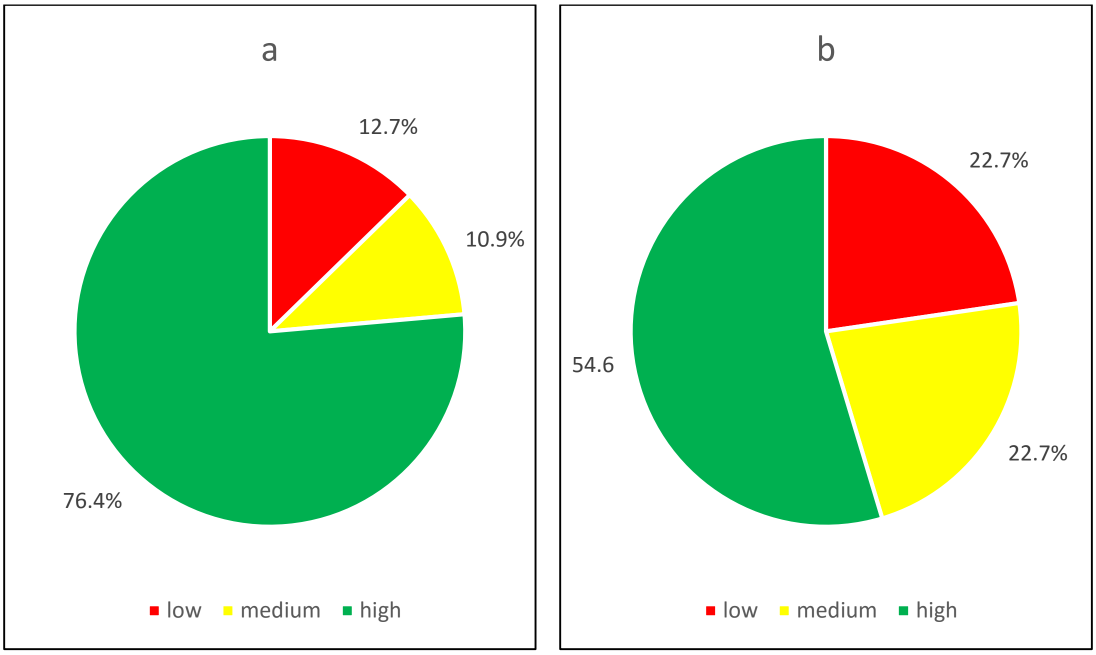


Figure 23. Comparison of frequency of available phosphorus in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

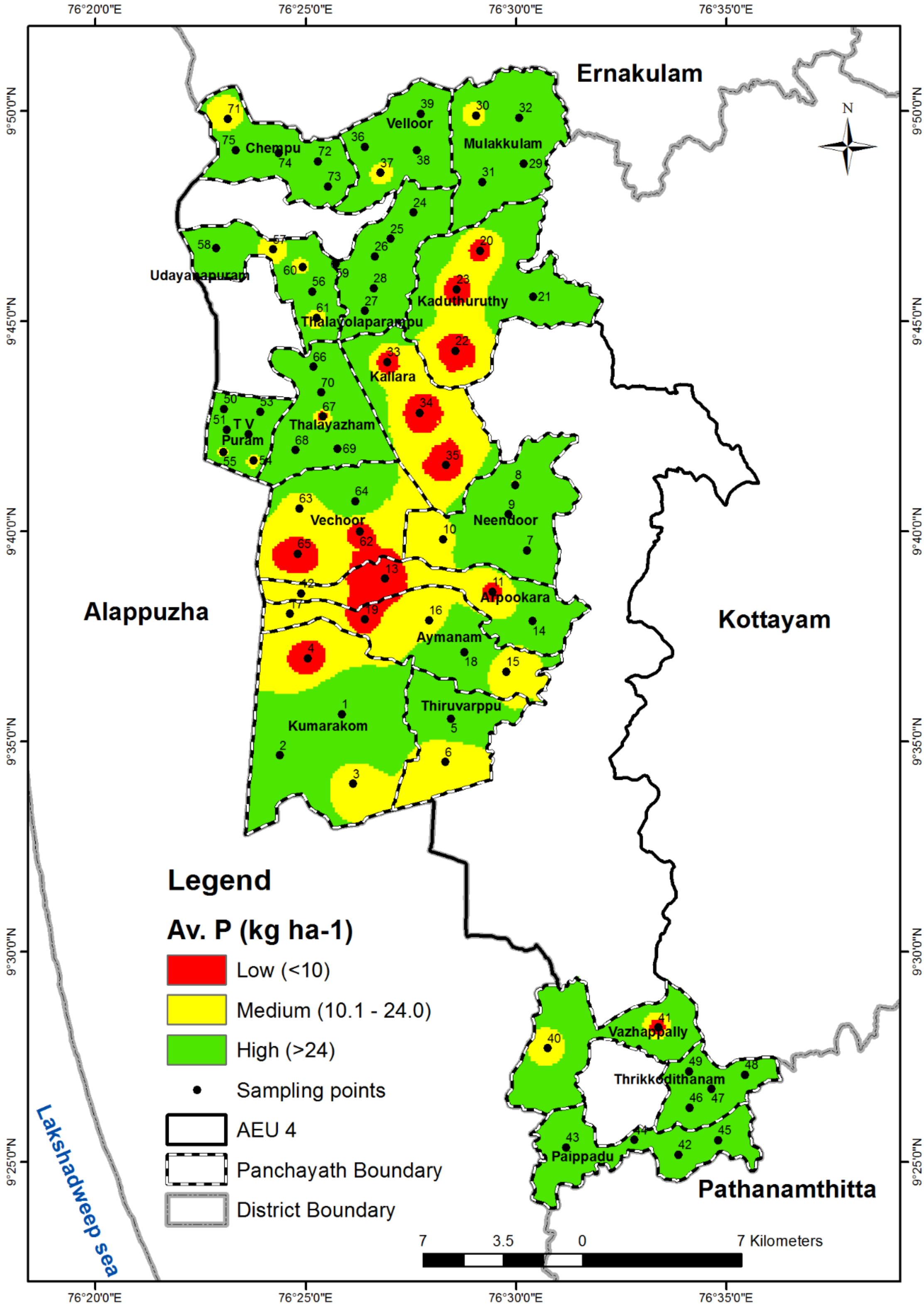


Figure 24. Spatial distribution of available phosphorous in post flood soils of AEU 4 of Kottayam district

5.1.2.6. Available potassium

Status of available potassium was reported to be high in 40 per cent of samples, medium in 32 per cent of samples and low in 28 percent of samples (Figure 25) whereas the pre flood data recorded 32.2 per cent, 36.6 per cent and 31.2 per cent respectively in high, medium and low fertility class (KSPB, 2013) (Figure 26)

There was an increase in fertility status after flood in the area. This may be due to the decomposition of straw of the standing crop at the time of flood. Saha *et al.* (2009) reported straw incorporation maintained K balance in soil. Similar increase in potassium content was opinioned by GOK, (GOK, 2018). The low availability of potassium in certain sites can be due to the leaching of potassium ions from the soil.as suggested by Igwe *et al.* (2008).

Spatial distribution of available potassium is presented in figure 27.

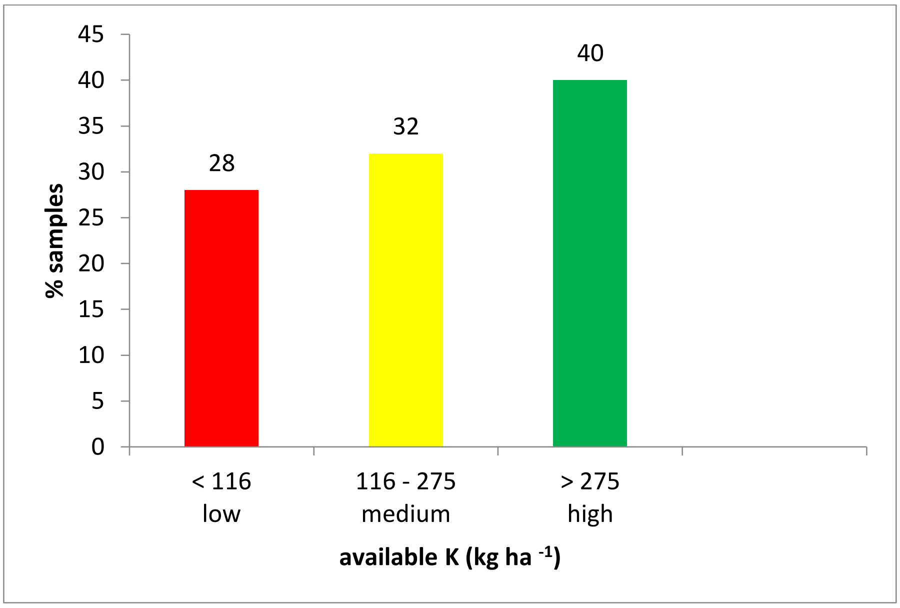
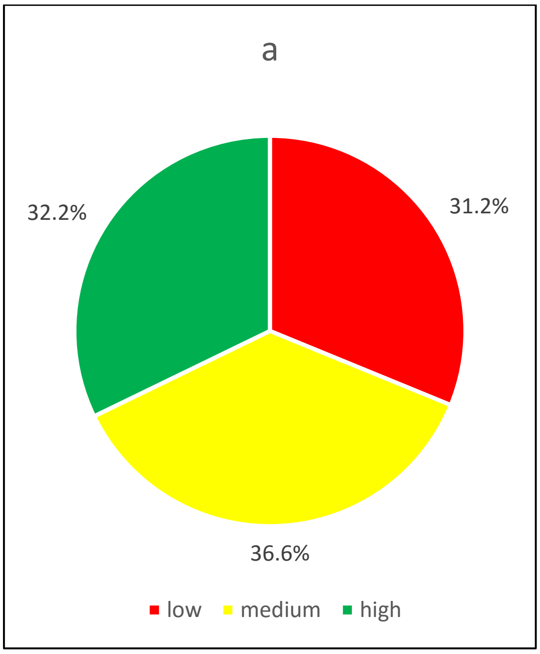


Figure 25. Frequency distribution of available potassium in post flood soils of AEU 4 of Kottayam district



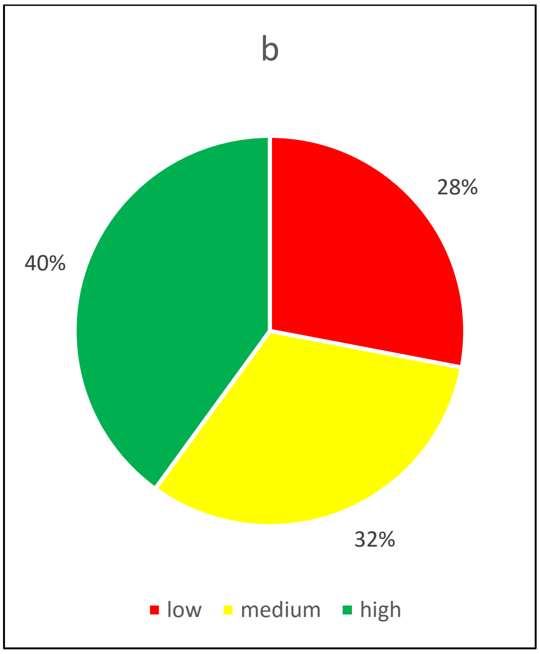


Figure 26. Comparison of frequency of available potassium in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

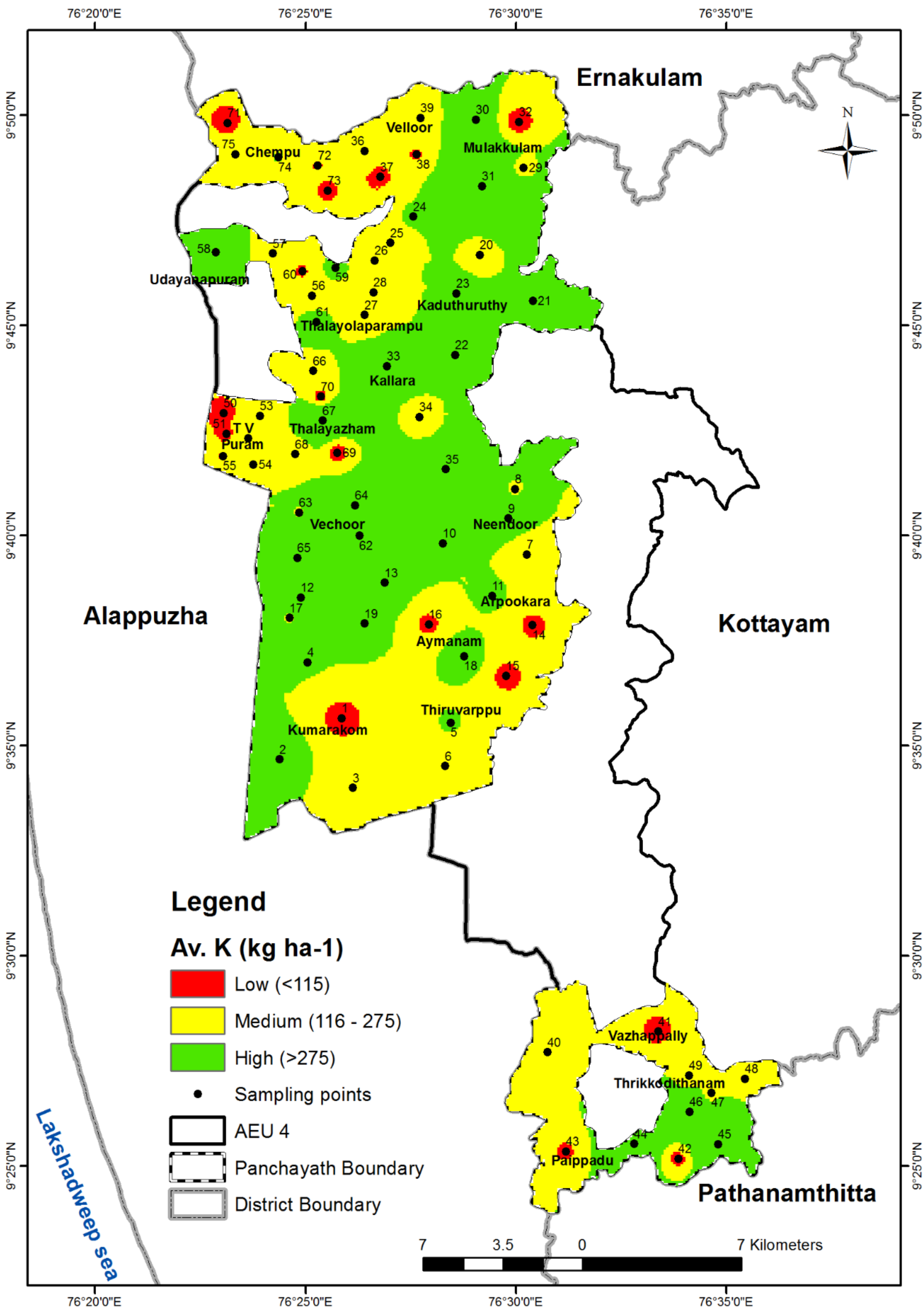


Figure 27. Spatial distribution of available potassium in post flood soils of AEU 4 of Kottayam district

5.1.2.7. Available calcium

Calcium content was adequate in 88 per cent of soil samples and 12 per cent samples were reported to be deficient (Figure 28) whereas pre flood data indicated 49.4 percent to be deficient and 50.6 to be adequate (KSPB,2013) (Figure 29). This indicates an increase in availability of Ca in post-flood soils.

The area under study is generally acidic in nature with soils having acid sulphate condition. The farmers were practicing proper liming to overcome the same. Hence, practice of liming followed by the farmers might be a reason for increased availability of calcium. Moreover, marine origin of these soils and seasonal sea water intrusion also might be responsible for increased calcium in the study area. Available calcium in post flood soils were adequate for agricultural purpose. Similar results of adequate calcium with which Ca ranged from 160 ppm to 1303 ppm was reported in post flood soils. (GOK, 2018)

Kabeerthumma and Patnaik (1978) observed a rise in exchangeable Ca in flooded soil which was attributed to the increased solubility due to combined effect of CO_2 and increased pH. Beena (2005) reported similar observation where calcium content ranged from 514 to 1456 mg kg^{-1} in various parts of Kuttanad and suggested the presence of lime shell deposits in some areas.

Spatial distribution of available calcium in the study area is depicted in figure 30.

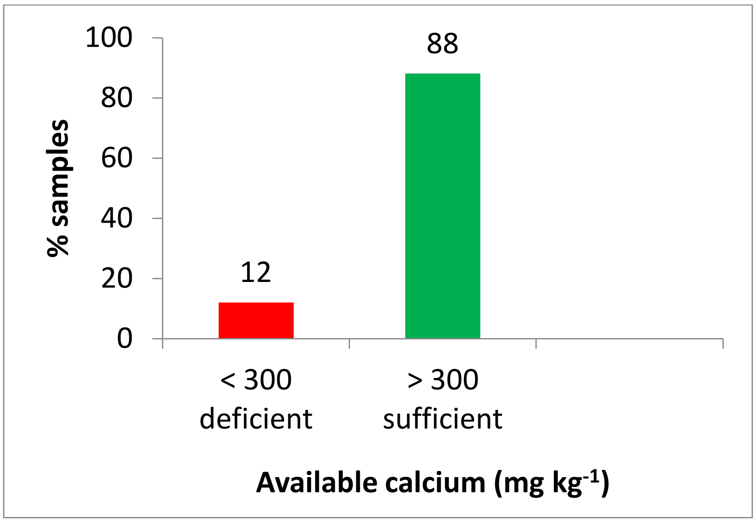


Figure 28. Frequency distribution of available calcium in post flood soils of AEU 4 of Kottayam district

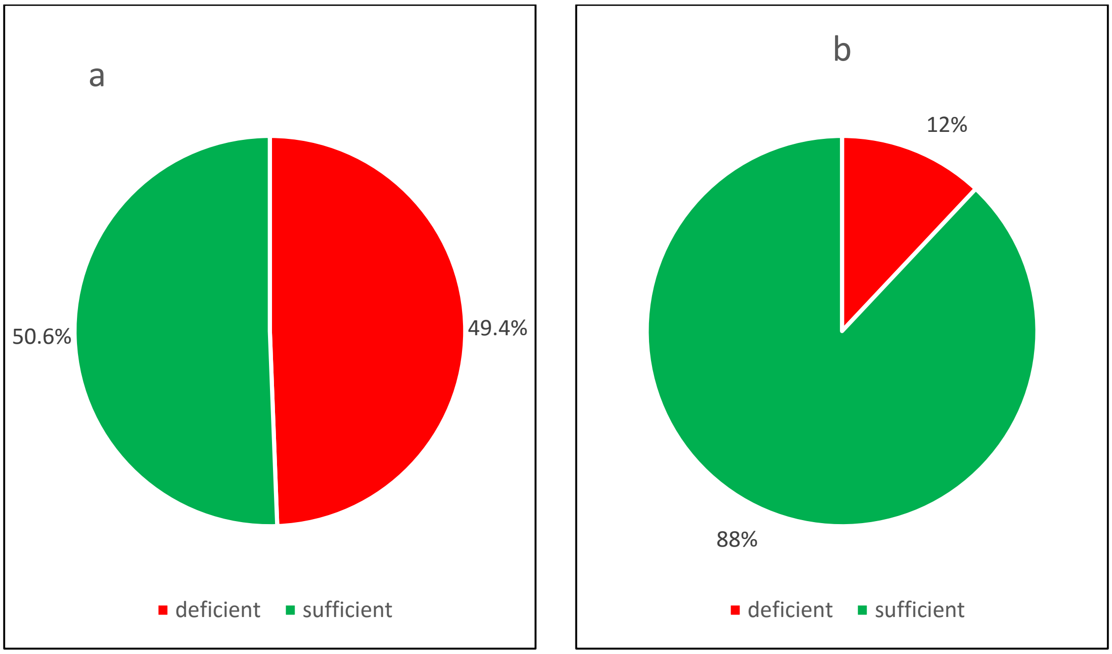


Figure 29. Comparison of frequency of available calcium in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

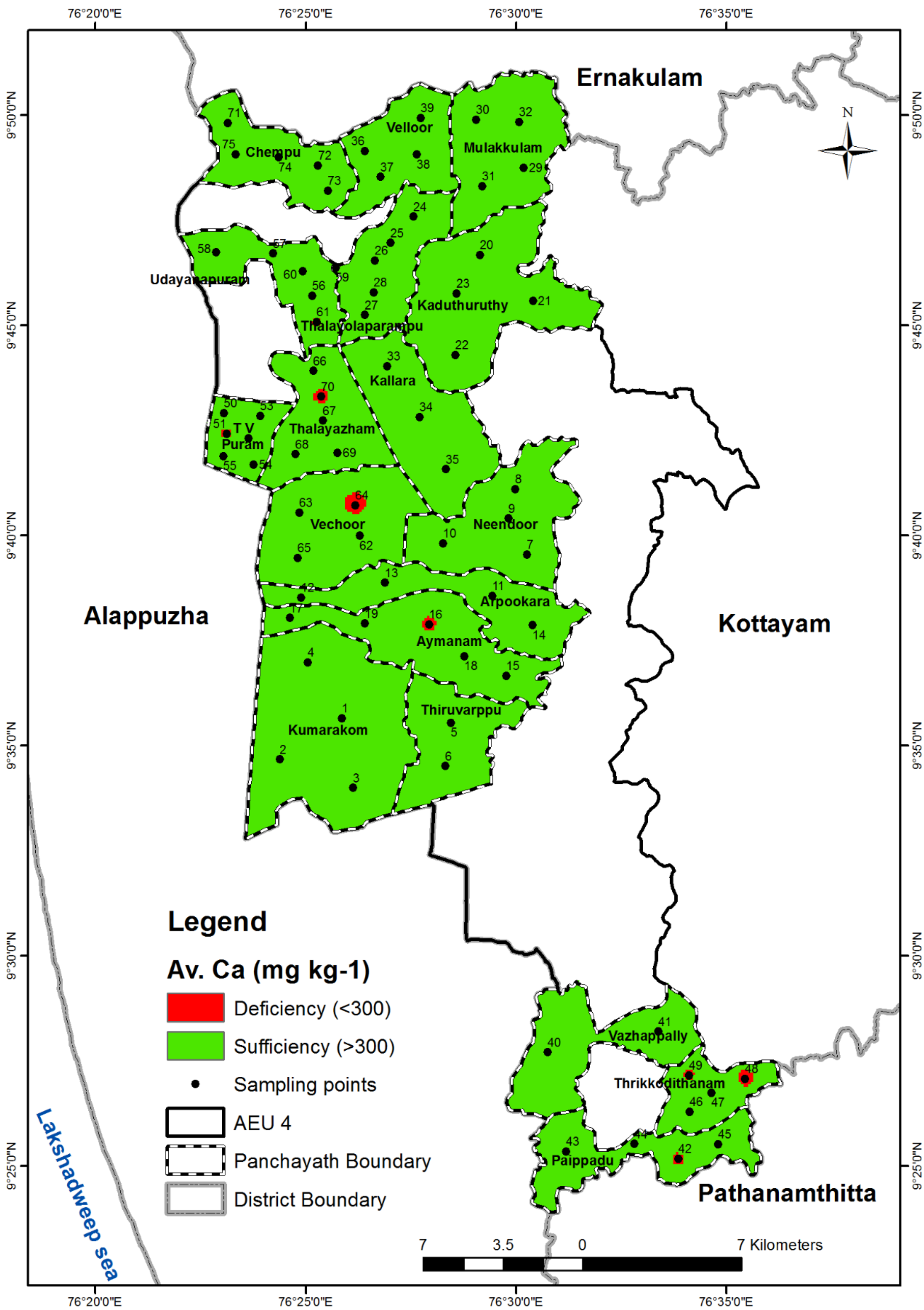


Figure 30. Spatial distribution of available calcium in post flood soils of AEU 4 of Kottayam district

5.1.2.8. Available magnesium

When compared to pre-flood data where 68 per cent samples were deficient and 32 per cent were sufficient (Figure 31), post flood analysis shown deficiency in only 41.3 per cent of samples and sufficiency in 58.7 per cent samples in available magnesium (KSPB, 2013), (Figure 32)

GOK also reported an increased magnesium content in low lands of Kottayam in the post flood soils which ranged from 131.9 to 540 mg kg^{-1} (GOK, 2018) The increased magnesium in these area was mainly due to the interest of farmers in application of dolomite as a liming material in the soil.

Beena (2005) reported the magnesium availability in Kuttanad soils to range between 212 to 927 ppm. The hydration and hydrolysis by the action of water on submergence increases the availability of calcium and magnesium.

Spatial distribution of available magnesium in the study area is presented as figure 33.

5.1.2.9. Available sulphur

High availability of sulphur was observed in the AEU, with 81.3 per cent samples being sufficient and 18.7 per cent being deficient (Figure 34) The high availability in sulphur may be due to immense presence of pyrites in acid sulphate soils of Kuttanad. More amount of sulphate released may also release H^+ ions which can increase acidity which was confirmed by the significant negative correlation of sulphur with pH.

The pre-flood data of KSPB, (2013) reported 92.1 per cent to be adequate in available sulphur. (figure 35) On comparing to the present data, sulphur showed a lower value which may be due to the leaching of sulphate ions but in general, the area was sufficient in available sulphur which is mainly due to the presence of pyrites. The post flood analysis of soils by soil survey and soil conservation also reported the area to be high in available sulphur where the values ranged from 2.02 ppm to 1376 ppm. (GOK, 2018) Spatial distribution of available sulphur is presented as figure 36

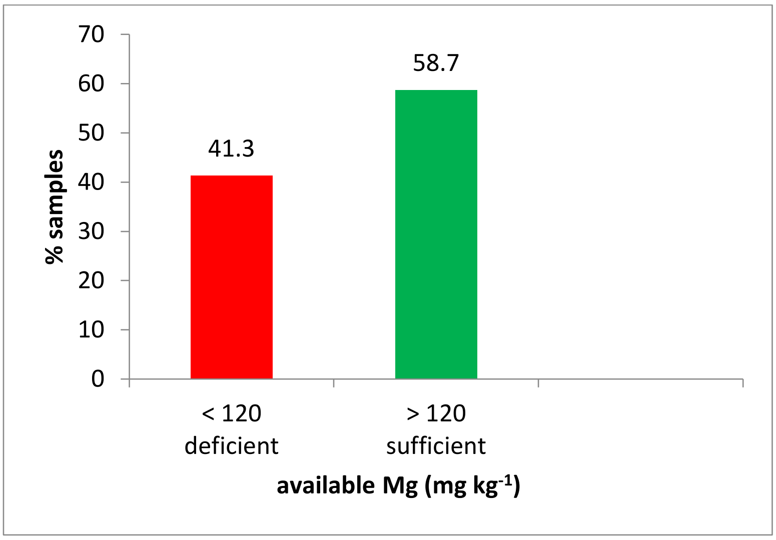


Figure 31. Frequency distribution of available magnesium in post flood soils of AEU 4 of Kottayam district

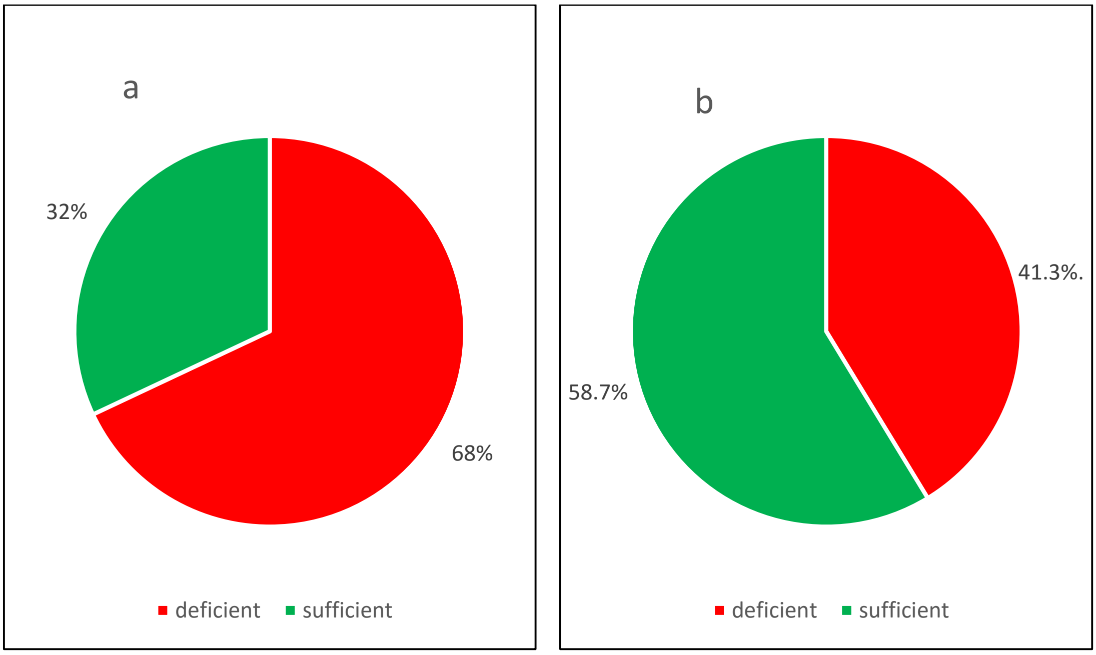


Figure 32. Comparison of frequency of available magnesium in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

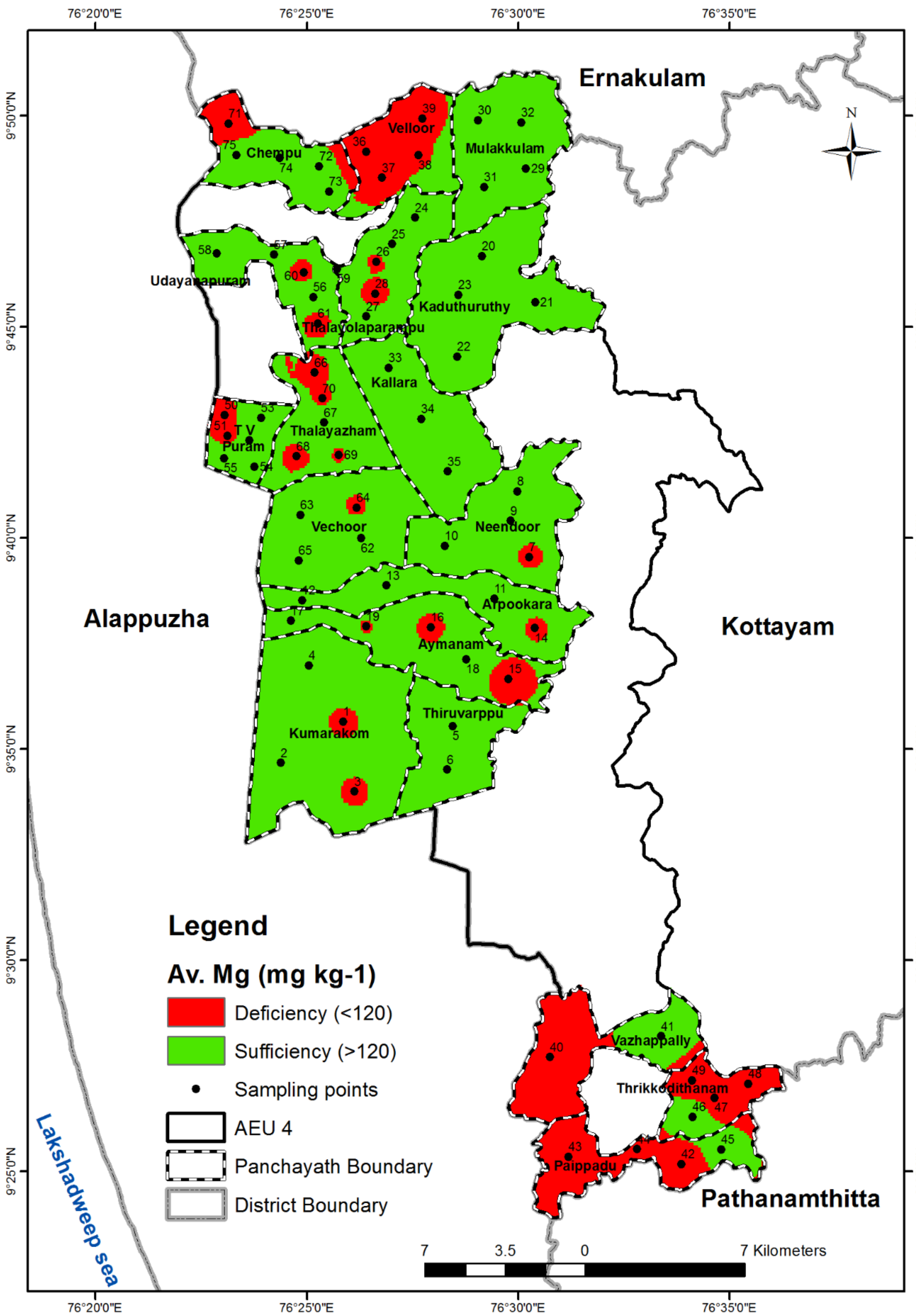


Figure 33. Spatial distribution of available magnesium in post flood soils of AEU 4 of Kottayam district

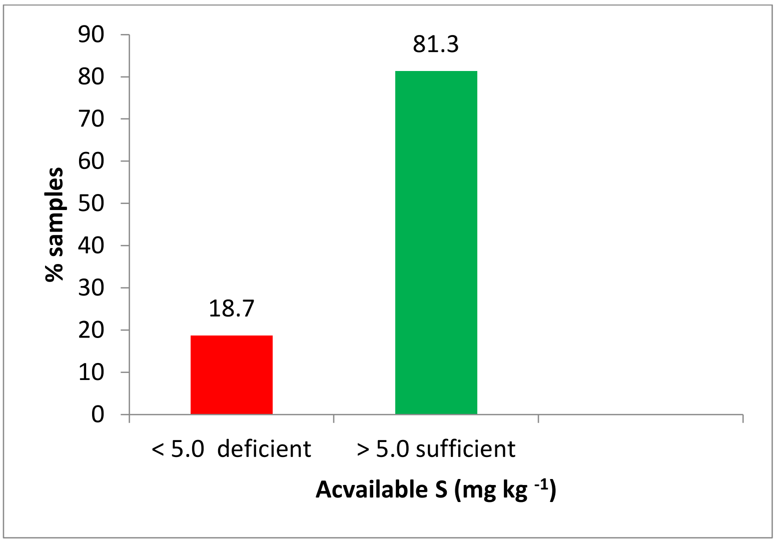


Figure 34. Frequency distribution of available sulphur in post flood soils of AEU 4 of Kottayam district

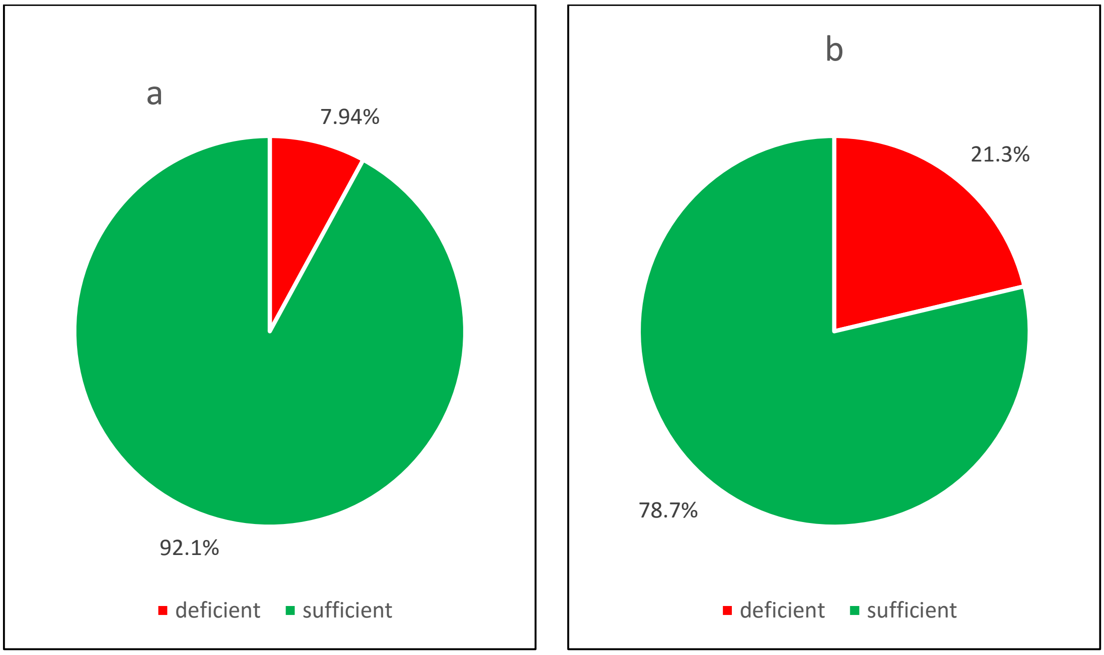


Figure 35. Comparison of frequency of available sulphur in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

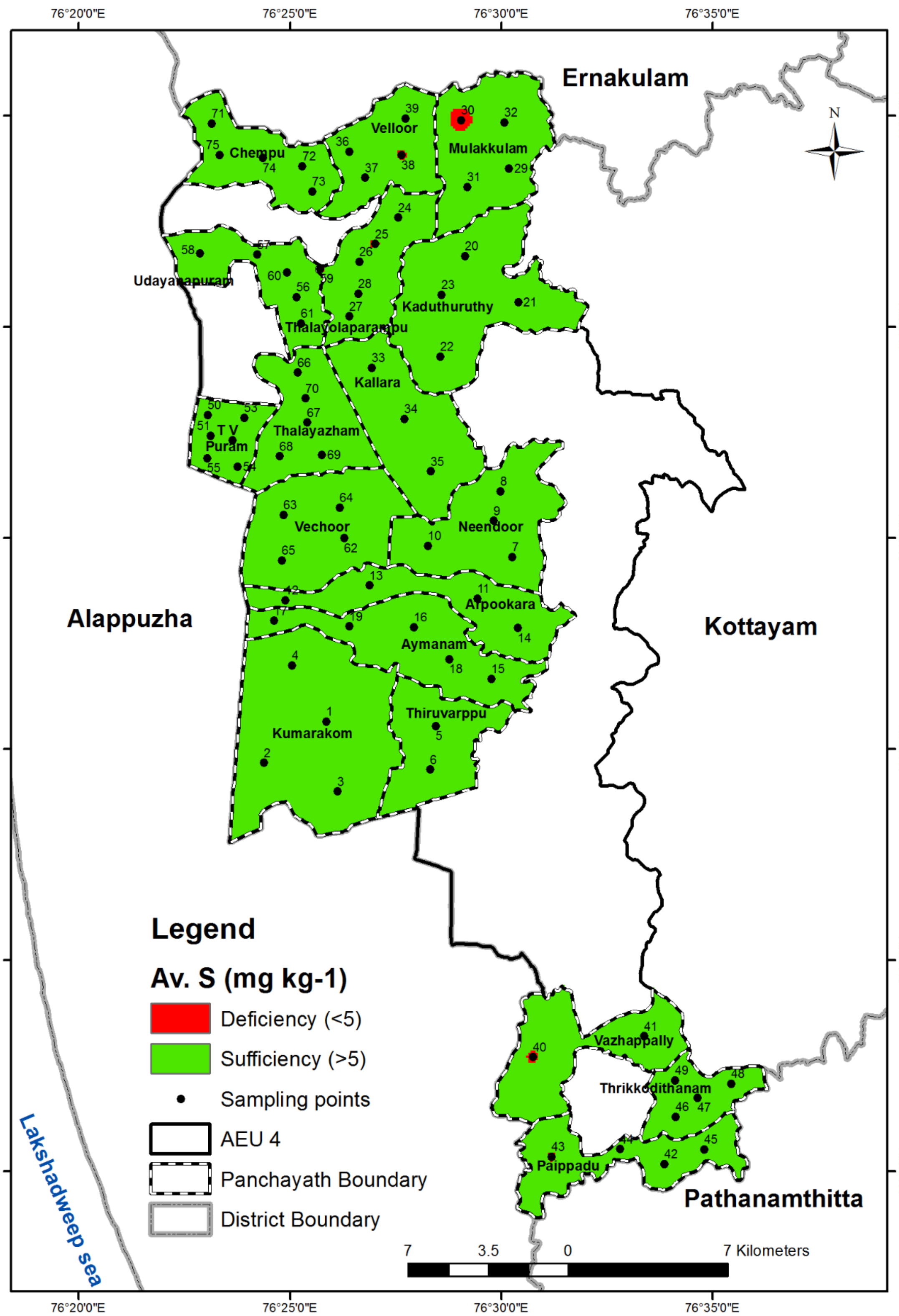


Figure 36. Spatial distribution of available sulphur in post flood soils of AEU 4 of Kottayam district

5.1.2.10. Available boron

Boron content in the soils were generally found to be deficient (78.7 per cent) and 21.3 per cent were adequate (Figure 37) whereas pre flood data (Figure 38) (KSPB, 2013) signified only 57.4 per cent as deficient and 42.6 as sufficient. This signifies that boron deficiency has increased in the post-flood soil. Being highly mobile, boron in many parts might have got washed away with the flood waters which aggravated the boron deficiency in soil. Acidic leaching nature of soils in Kuttanad might be responsible for increased boron deficiency.

Soil samples of Kallara on analysis recorded the highest available boron. Results obtained from a study conducted by George (2011) reported boron content from 0.26 ppm to 3.12 ppm in Kerala.

Due to the high mobility of boron in soil, application of borax or its foliar spray at regular intervals can be done to overcome the deficiency.

Spatial distribution of available boron in post flood soils of AEU 4 of Kottayam district is presented in figure 39.

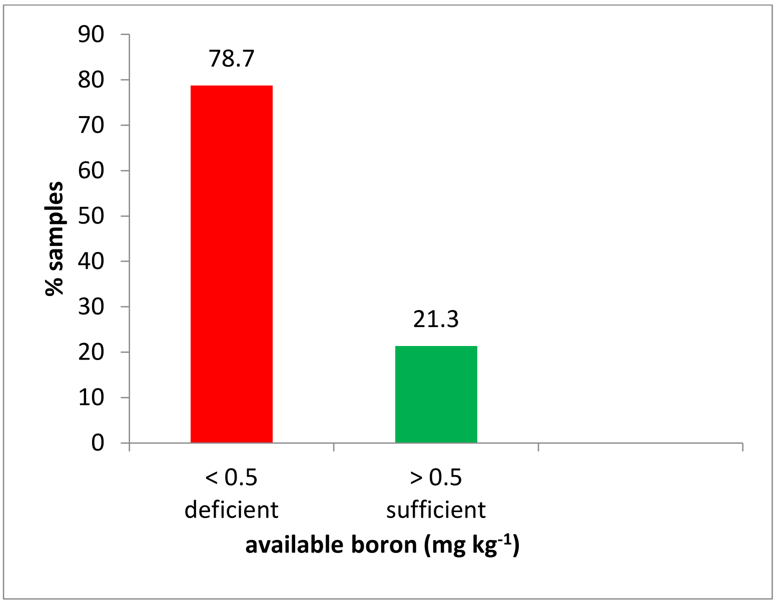


Figure 37. Frequency distribution of available boron in post flood soils of AEU 4 of Kottayam district

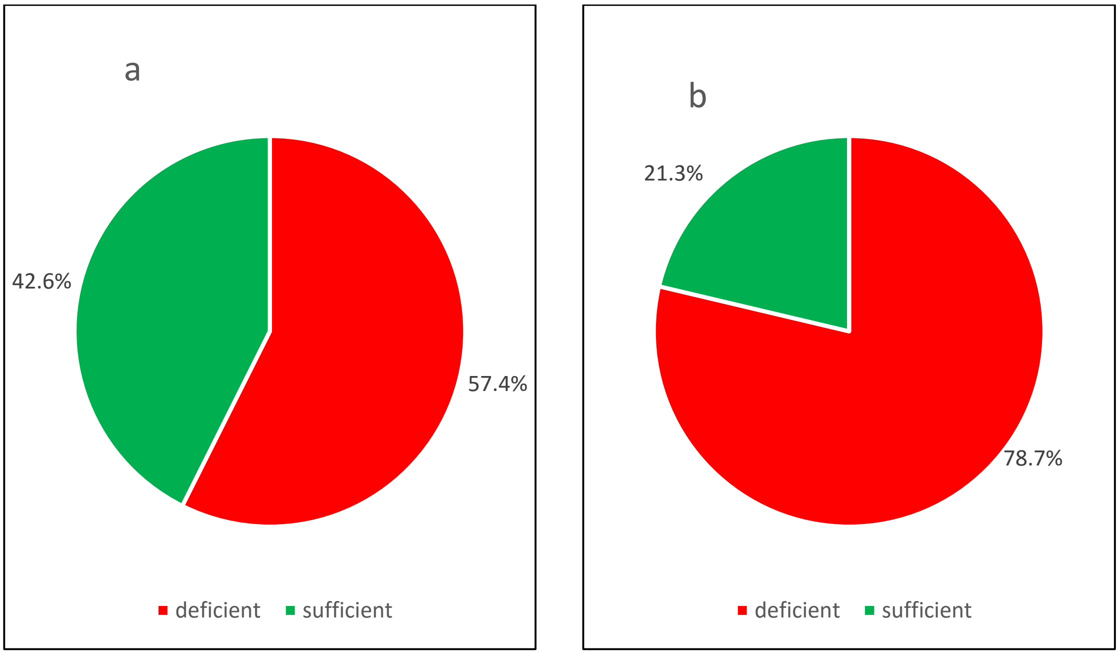


Figure 38. Comparison of frequency of available boron in pre-flood (a) and post-flood (b) soils of AEU 4 in Kottayam district

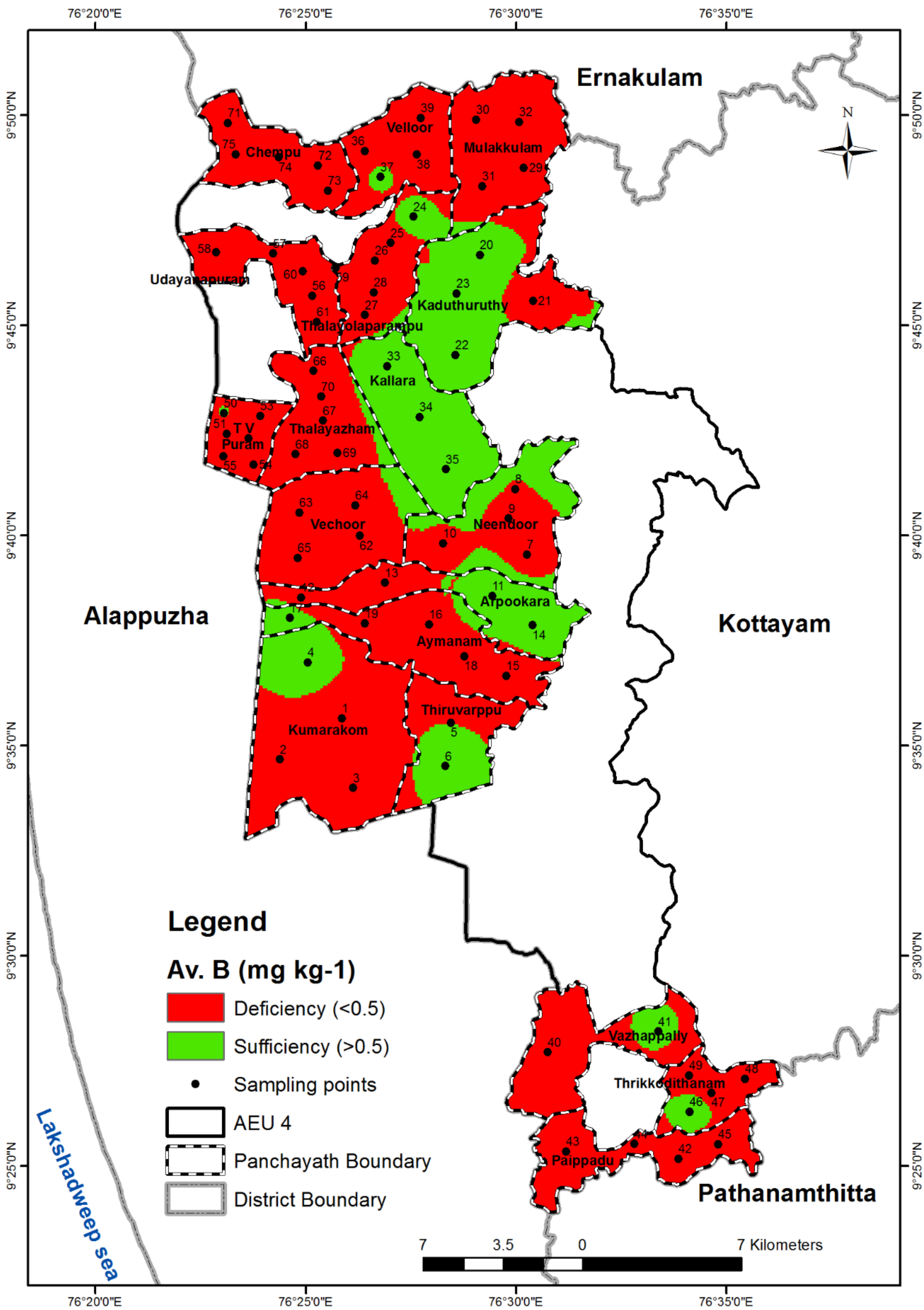


Figure 39. Spatial distribution of available boron in post flood soils of AEU 4 of Kottayam district

5.1.3. Biological attribute

5.1.3.1. Acid phosphatase activity

The study on activity of acid phosphatase revealed that, 20 per cent of samples showed an activity less than 10 µg p-nitrophenol g^{-1} soil h^{-1}, 41.3 samples recorded 10–25 µg p-nitrophenol g^{-1} soil h^{-1}, 26.7 per cent showed an activity between 25 – 50 µg p-nitrophenol g^{-1} soil h^{-1} and 12 per cent samples above 50 µg p-nitrophenol g^{-1} soil h^{-1} (Figure 40)

Kalembasa and Kuziemska (2010) observed an increased activity of phosphatase on organic fertilization. This may be the reason of increased activity acid phosphatase in the study as the area was rich in organic carbon.

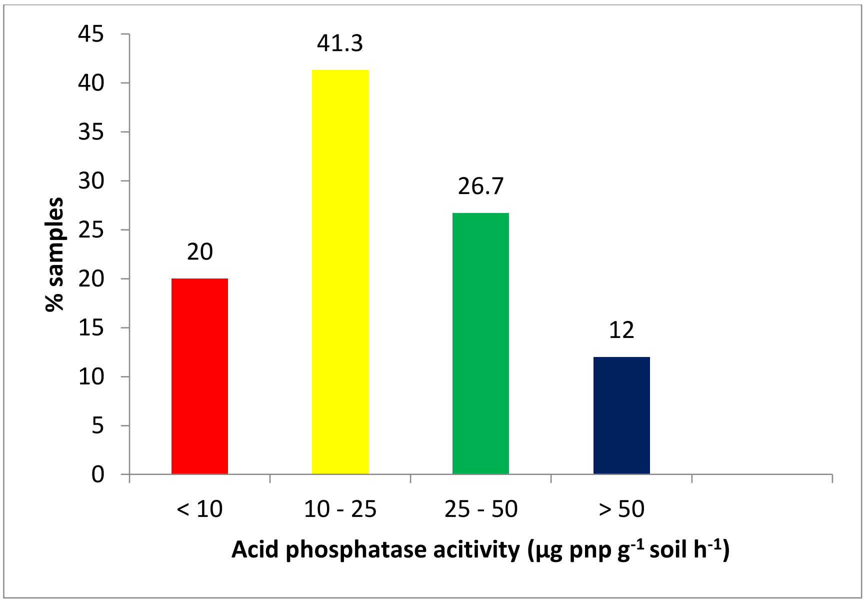


Figure 40. Frequency distribution of acid phosphatase activity in post flood soils of AEU 4 of Kottayam district

5.2. SQI AND RSQI

Principal component analysis (PCA) was employed to arrive at a minimum dataset. The MDS in the present study consisted of seven parameters which include organic carbon, available nitrogen, phosphorus, potassium, calcium, per cent sand and per cent silt. Through scoring and weightage of the MDS, SQI was computed for each site.

The RSQI values computed from SQI were used to categorize the soil to poor, medium and high soil quality. It was observed that 65 per cent of the samples fell into medium soil quality, 33.3 per cent as good and 2.67 per cent as poor (Figure 41) Neendoor panchayat which reported the highest RSQI was having high status of organic carbon, phosphorus, potassium, and calcium in the minimum data set which rendered them a high quality and Vazhapally panchayat that recorded lowest RSQI was low in nitrogen, phosphorous and potassium.

The increase in soil quality in majority of the areas were mainly due to the increased organic matter content and also may be due to the flood water deposition of silt with organic debris. Since soil organic carbon is linked to many other physical, chemical and biological attributes, it is considered as a keystone soil quality indicator (Reeves, 1997). Spatial distribution of RSQI is presented in Figure 42.

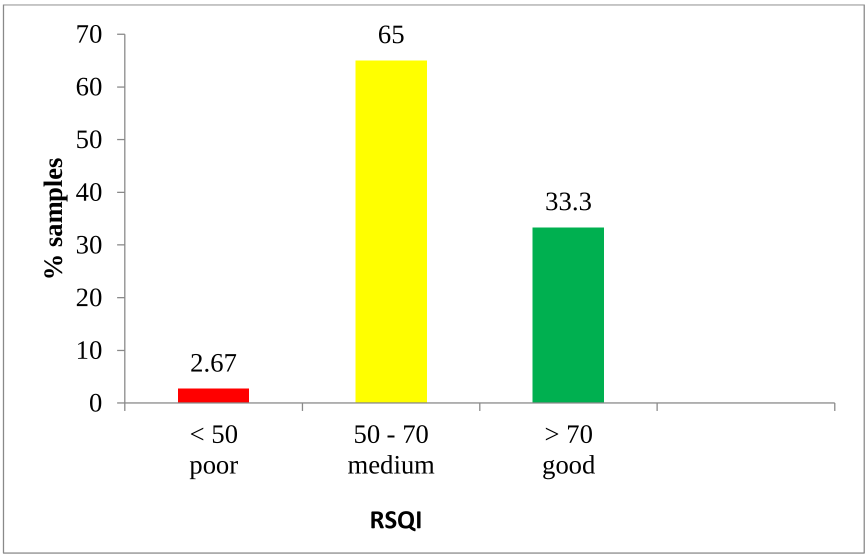


Figure 41. Frequency distribution of RSQI in post flood soils of AEU 4 of Kottayam district

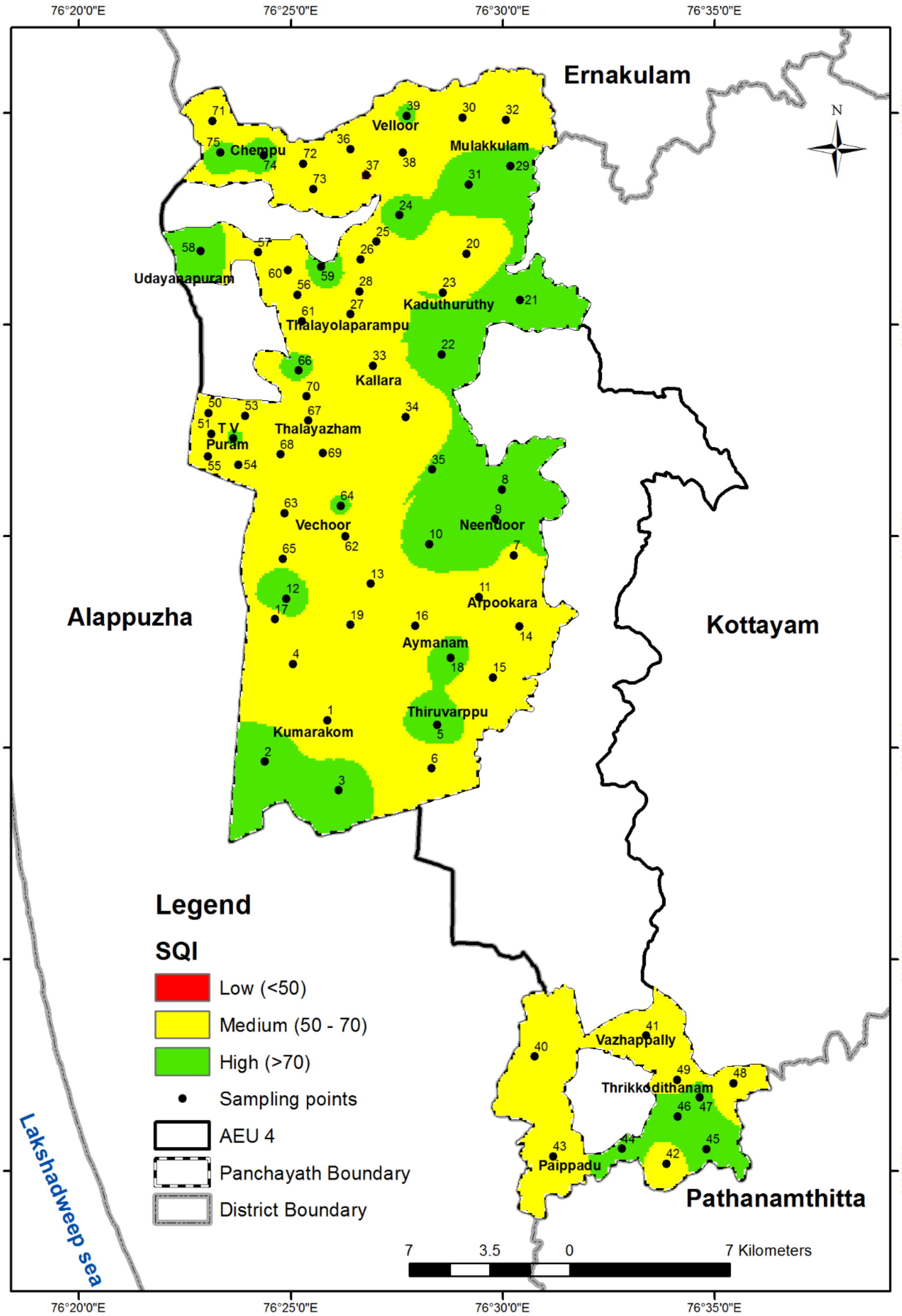


Figure 42. Spatial distribution of SQI in post flood soils of AEU 4 of Kottayam district

5.3. NUTRIENT INDEX (NI)

Nutrient index values were calculated for organic carbon and available primary nutrients. The nutrient index values obtained represented the nutrient status of the area. A high value of nutrient index represented high fertility status of that particular nutrient. Nutrient index values were high for organic carbon, low for available nitrogen, and medium for available phosphorus and available potassium.

The spatial distribution of nutrient indices of organic carbon, available nitrogen, available phosphorus and available potassium are depicted in Figure 44,45, 46 and 47 respectively.

5.4. LAND QUALITY INDEX (LQI)

Soil organic carbon stock was analysed using organic carbon per cent, bulk density and soil depth. The LQI was depicted based on SOCS. Land quality of 46.7 per cent samples were found to be very low and 38.7 per cent samples were low (Figure 43) This was mainly due to a decreased bulk density values and lower soil volume. Moderate to very high land quality was reported in 14.68 per cent samples where the content of organic carbon was sufficient to cope up with reduced values of bulk density.

Spatial distribution of LQI of the area under study is presented in figure 48

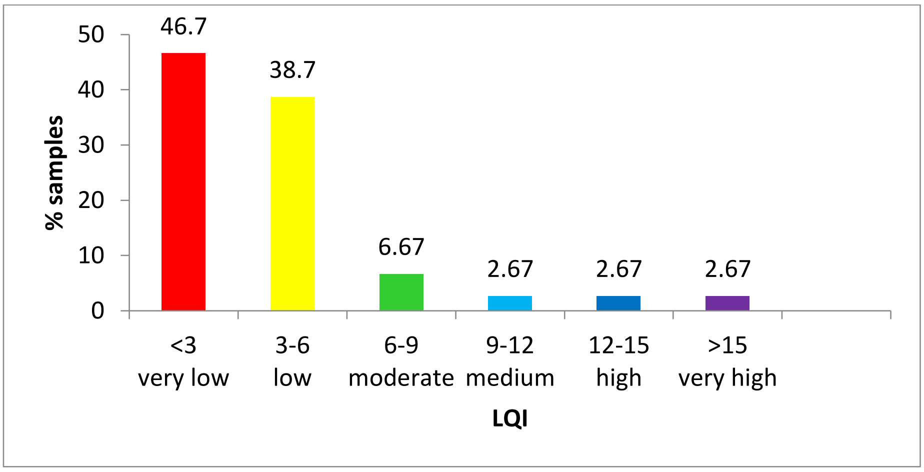


Figure 43. Frequency distribution of land quality index in post flood soils of AEU 4 of Kottayam district

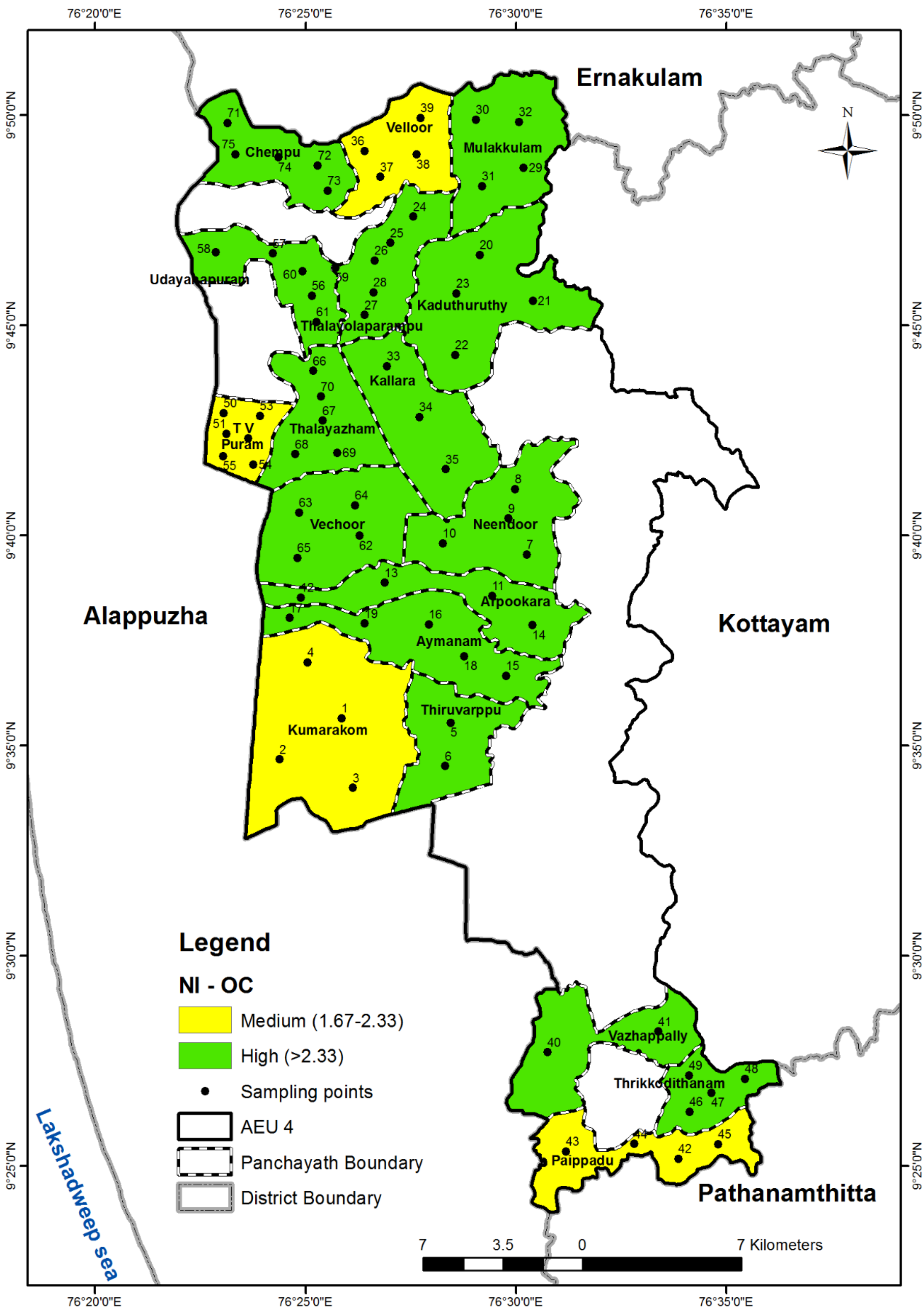


Figure 44. Spatial distribution of nutrient indices for organic carbon in post flood soils of AEU 4 of Kottayam district

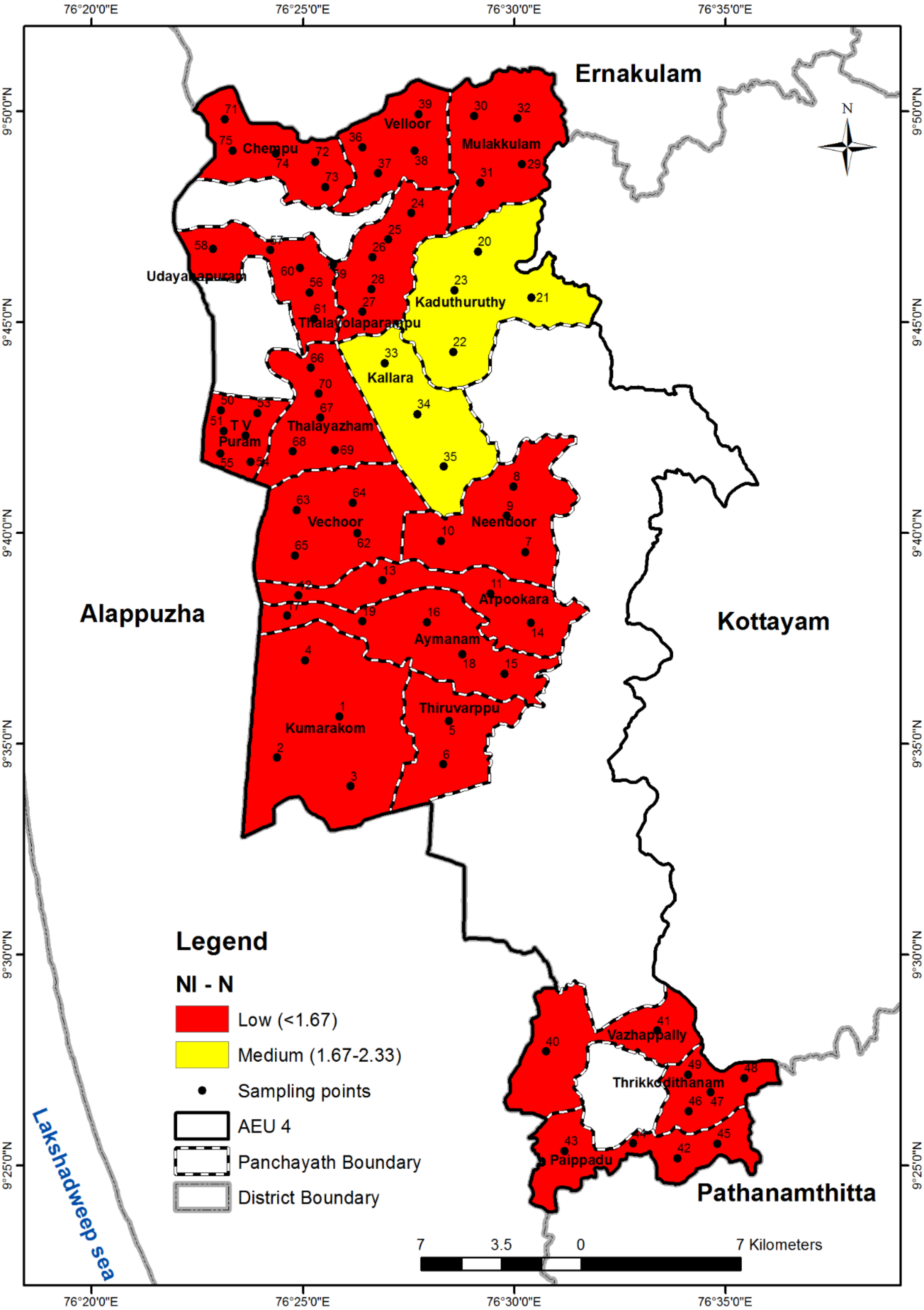


Figure 45. Spatial distribution of nutrient indices of available nitrogen in post flood soils of AEU 4 of Kottayam district

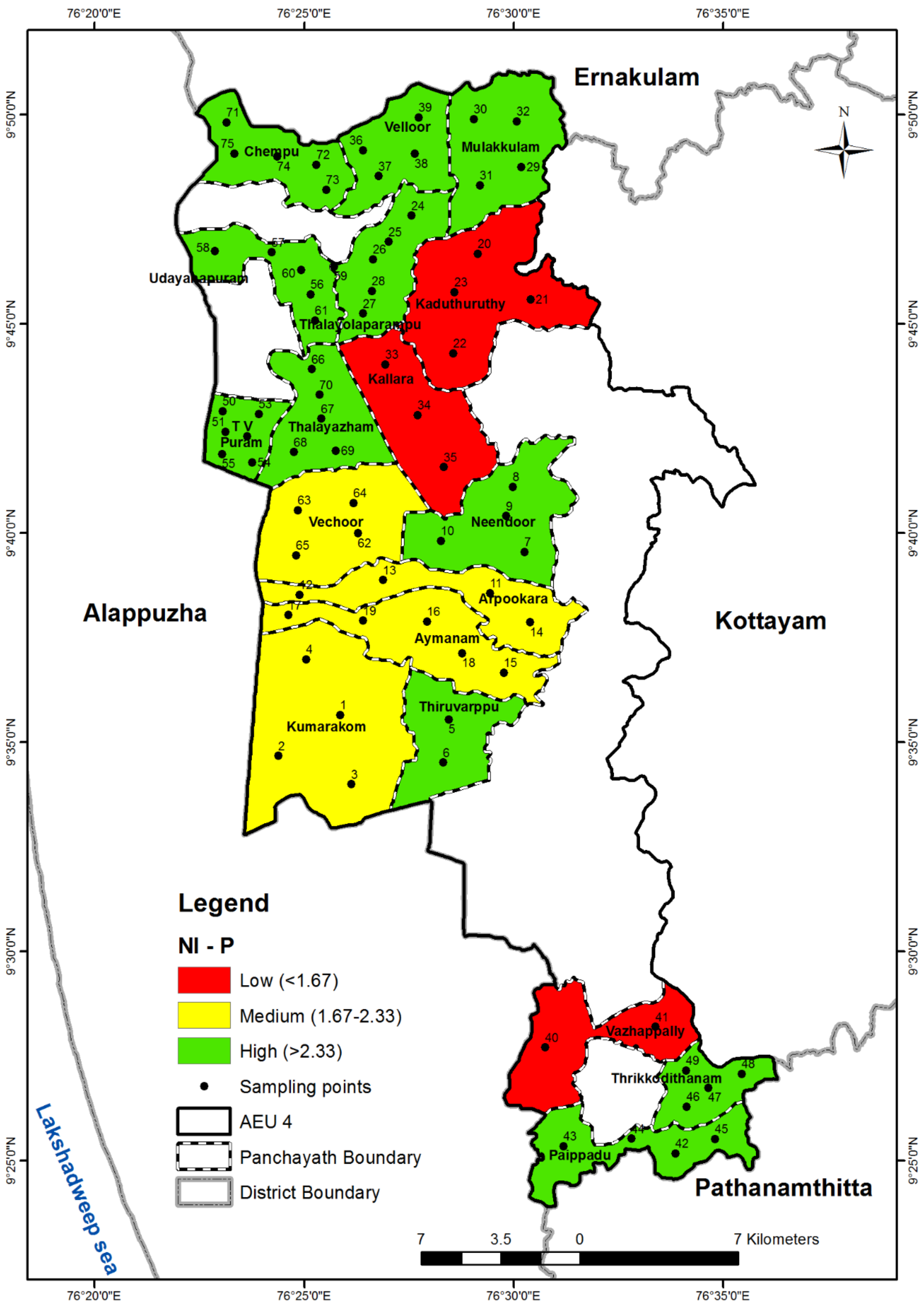


Figure 46. Spatial distribution of nutrient indices of available phosphorus in post flood soils of AEU 4 of Kottayam district

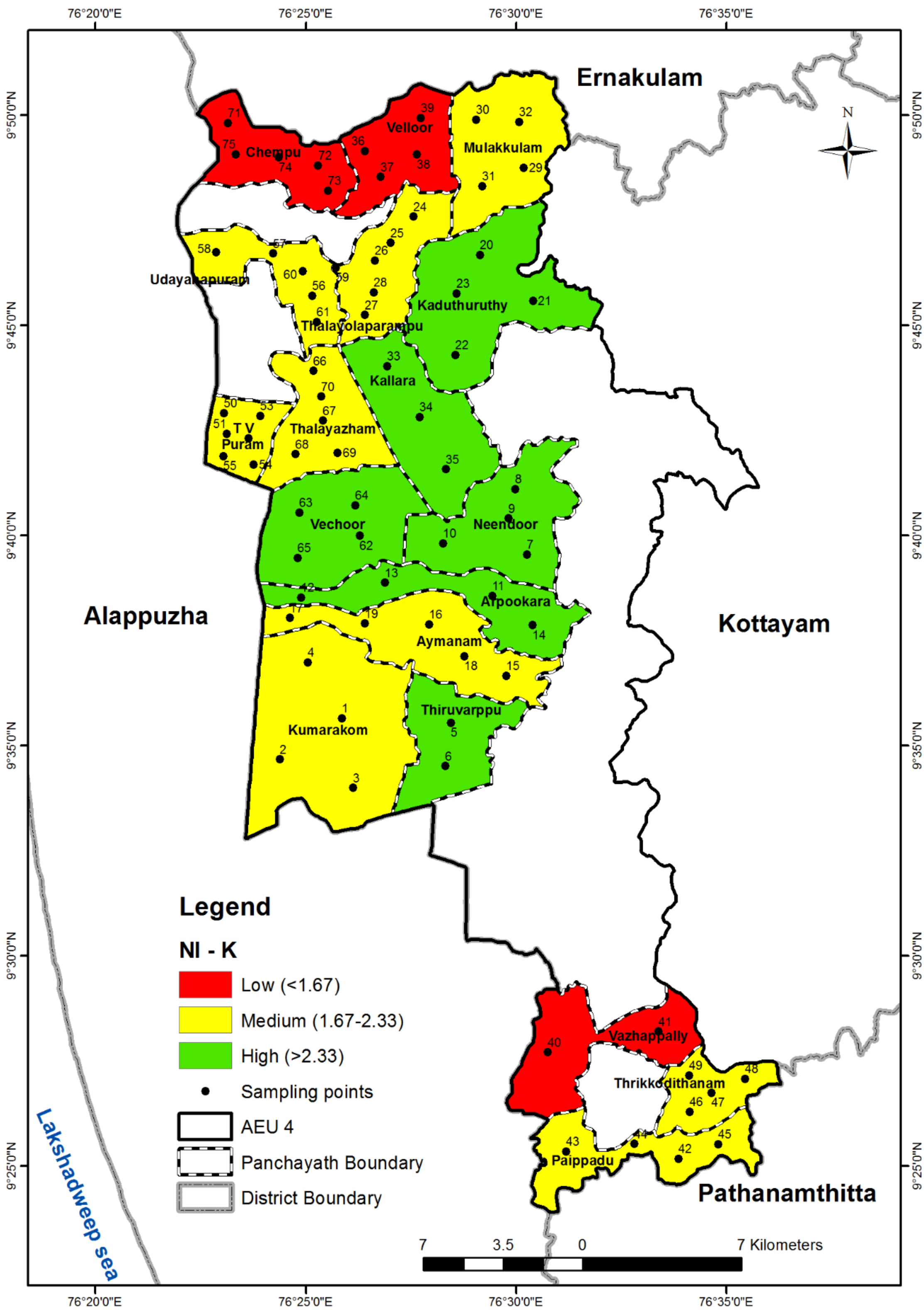


Figure 47. Spatial distribution of nutrient indices of available potassium in post flood soils of AEU 4 of Kottayam district

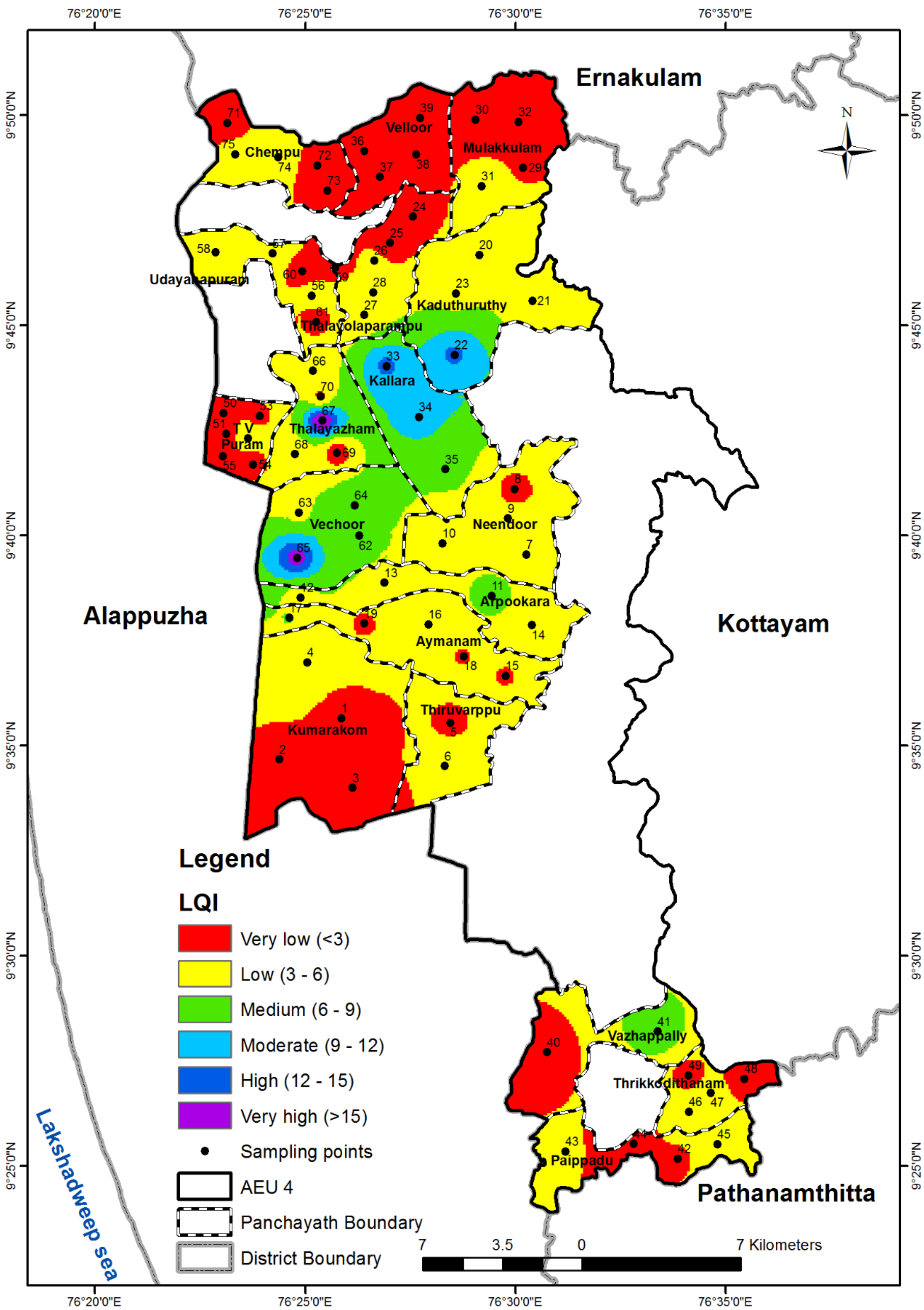


Figure 48. Spatial distribution of land quality index in post flood soils of AEU 4 of Kottayam district

5.4. COMPARISON OF PRE-FLOOD AND POST-FLOOD SOIL CHEMICAL PROPERTIES

AEU 4 (Kuttanad) in Kottayam district is subjected to flooding frequently in monsoon season. The recent floods in August, 2018 revealed that flash floods are inevitable in the Kuttanad wetlands and affected livelihood, agriculture and other allied enterprises. Based on the information provided from the Krishi bhavans, 18 panchayats from four different blocks were identified and the analysed data were compared with the pre-flood data (KSPB,2013)

The percentage of samples in the category of extremely acid soils, very strongly acid soils, strongly acid soils have reduced and in ultra-acid, moderately acid, slightly acid and neutral increased in post-flood scenario. The increased acidity can be due to the production of H^+ ions by the oxidation of pyrites or organic acids from the decomposition of organic matter.

An increase in organic carbon was noticed in the area compared to the pre flood condition as the per cent samples in high fertility class raised from 32.8 per cent to 58.7 in post flood soils and also a decrease in low fertility class is observed.

Phosphorous availability in general was high in most of the areas except Kallara panchayat but the percentage of samples in low fertility class showed an increase. The availability of potassium has increased in the post flood soils where the percentage number of samples in the high category had increased from 32.2 per cent to 40 per cent.

Ca, Mg and S was found to be optimum for crop production. The per cent samples with Ca and Mg in adequate range was increased by 37.4 per cent and 26.7 respectively. Availability of sulphur was deficient in 18.3 per cent of samples in post-flood soils whereas it was deficient only in 7.94 per cent in pre-flood condition.

Boron was also found to reduce after the flood. The per cent samples deficient in available boron increased to 78.7% (post-flood) from 57.4 per cent (pre-flood).

5.6. MANAGEMENT STRATEGIES IN AEU 4 (KOTTAYAM DISTRICT) IN THE POST-FLOOD SCENARIO

Many changes have occurred in the post flood soils of the study area in terms of physico chemical properties compared to the pre flood soils which was dealt in section 5.6. Hence there is a need to change the management strategies based on the altered properties.

Acidity was found to be a major problem in the soils of the study area even though the percentage of samples in neutral range increased. Flooding, liming and washing, surface and subsurface drainage can be employed to overcome acidity problems. Dolomite can be used in those areas where Ca and Mg are found to be deficient.

Application of nitrogenous fertilizers has to be enhanced as the area was deficient for availability of nitrogen. Application of phosphorus fertilizers can be cut down as majority of the areas were recorded to have medium to high fertility status for P. Kallara panchayat that recorded the lowest P availability must follow the application of phosphorous fertilizers. Since the soil available potassium was high to medium, and in places where it is found to be high application can be reduced.

Among the secondary nutrients, Ca and S availability was adequate in all the panchayats. The Mg status of soil was observed to be deficient in Velloor, Vazhapally, Paippad and Thrikodithanam panchayat. Application of dolomite or magnesium sulphate can be recommended for the management of Mg deficiency in these areas.

Boron fertilizers can be recommended in all the 18 panchayats (except Thiruvarp, Arpookara, Kaduthuruthy, Kallara and Vazhapally panchayats) where the available boron was found to be in deficient range.

5.6.1. Panchayat wise management strategies as per KAU recommendations

The recommendations provided here based on KAU POP (2016). Fertility class as per KAU POP is provided in appendix V.

Table 25. Fertilizer recommendations for panchayats as per rating of KAU POP,2016

Panchayat	Lime (Kg ha^{-1})	as % POP			$MgSO_4$ (Kg ha^{-1})	Borax (Kg ha^{-1})
		N	P	K		
Kumarakom	350	78	25	71	Adequate	10
Thiruvarp	250	63	48	71	Adequate	Adequate
Neendoor	100	71	25	48	Adequate	10
Arpookara	600	54	94	48	Adequate	Adequate
Aymanam	600	54	48	60	Adequate	10
Kaduthuruthy	600	54	71	48	Adequate	Adequate
Thalayolaparambu	350	71	25	83	Adequate	10
Mulakkulam	250	71	25	25	Adequate	10
Kallara	1000	54	128	25	Adequate	Adequate
Velloor	250	84	25	94	80	10
Vazhapally	850	54	117	106	80	Adequate
Paippad	250	71	25	25	80	10
Thrikodithanam	350	71	25	60	80	10
T.V.Puram	250	84	25	94	Adequate	10
Udayanapuram	350	71	25	48	Adequate	10
Vechoor	850	54	83	25	Adequate	10
Thalayazham	600	54	25	48	Adequate	10
Chempu	250	78	25	83	Adequate	10

Kumarakom

The mean value for pH was 5.43 for the panchayat hence a lime application @350 kg ha^{-1} is recommended. Nitrogen @ 78% of the POP recommendation can be done. Availability of phosphorus was high hence phosphorus @ 25% of POP recommendation can be done. Potassium can be recommended @ 71% of POP recommendation of KAU can be suggested. Boron deficiency can be mitigated through the application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Thiruvarp

Liming @250 kg ha^{-1} is recommended as the soil was moderately acidic. Nitrogen application @ 63% of POP recommendation can be done. The mean value of phosphorus was 24.1 kg ha^{-1} and application of 48 % of POP recommendation can be suggested and potassium @71% of POP is also recommended. Magnesium, sulphur and boron was found to be sufficient.

Neendoor

Liming @100 kg ha^{-1} is recommended as the soil was slightly acidic.71% of KAU POP can be recommended for nitrogen. The application of 25 % of POP recommendation for P and 48% of POP recommendation for K can be done. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Arpookara

The soils were found to be very strongly acidic with mean 4.57 hence liming @ 600 kg ha^{-1} is recommended. Nitrogen @ 54 % of POP recommendation can be suggested. Application of P as 94% of POP recommendation and K as 48% of POP recommendation can be done. Magnesium, sulphur and boron was found to be sufficient.

Aymanam

Liming @ 600 kg ha^{-1} as the soils were reported to be very strongly acidic in reaction. Application of Nitrogen @ 54% of POP can be done. Application of P and K as 48% and 60% of POP respectively can be recommended. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Kaduthuruthy

The mean value for pH was 4.69 and a liming of 600 kg ha^{-1} is recommended. Nitrogen @ 54 % of KAU POP can be recommended. Application of P and K as 71% and 48% of POP respectively can be recommended. Secondary nutrients and boron was found to be sufficient,

Thalayolaparambu

Soils were reported to be strongly acidic hence application of lime @ 350 kg ha^{-1} is recommended. For nitrogen, 71% of POP can be recommended. Application of phosphorous as 25% of POP recommendation and application of potassium as 83% of POP recommendation can be done. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Mulakkulam

Liming @ 250 kg ha $^{-1}$ is recommended as the soils were moderately acidic. Nitrogen application @ 71% of POP recommendation can be done. Application of phosphorous can be reduced as 25% of POP recommendation. Potassium can also be recommended @ 25 % of KAU POP. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Kallara

The soils were ultra-acidic in reaction. The mean value for pH was 3.48 requiring a liming @ 1000 kg ha^{-1}. Nitrogen application @ 54% of KAU POP can be done. Phosphorus was found to be low hence application of P as 128 % of POP is recommended to ameliorate the deficiency. Application of K as 25% of POP is also recommended. Secondary nutrients and Boron was found to be sufficient.

Velloor

Liming @ 250 kg ha^{-1} is recommended as soil is moderately acidic. Application of nitrogen @ 84 % of POP can be recommended. Application of phosphorous can be reduced as 25% of POP recommendation can be done. Application of potassium as 94% of POP is recommended. Deficiency of magnesium can be corrected by the application of $MgSO_4$ @ 80kg ha^{1}. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Vazhapally

The soils were extremely acidic requiring liming @ 850 kg ha^{-1}. Nitrogen can be recommended @ 54% of POP. The availability of phosphorus was low requiring an application of P as 117% of POP recommendation. 109% of POP can be recommended for application of potassium. Deficiency of magnesium can be corrected by the application of $MgSO_4$ @ 80 kg ha^{1}. Boron was found to be sufficient.

Paippad

Liming @250 kg ha^{-1} is recommended as the soil was moderately acidic. Nitrogen @ 71% of POP recommendation can be done. Application of phosphorous can be reduced as 25% of POP recommendation. Potassium can also be applied @ 25% of POP recommendation. Deficiency of magnesium can be corrected by the application of $MgSO_4$ @ 80kg ha^1. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Thrikodithanam

Liming @ 350 kg ha^{-1} is recommended for strongly acidic soils as the mean value for pH was 5.02. Application of N can be recommended @71% of POP of KAU. Application of phosphorous can be reduced as 25% of POP recommendation. Application of potassium as 60% of KAU POP is recommended. Deficiency of magnesium can be corrected by the application of $MgSO_4$ @ 80kg ha^1. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

T.V. Puram

The soils were moderately acidic requiring a lime application @ 250 kg ha^{-1}. Nitrogen as 84% of POP can be recommended. Application of phosphorous can be reduced as 25% of POP recommendation. Application of potassium as 94% of POP recommendation can be done. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Udayanapuram

Soils of Udayanapuram panchayat was strongly acidic recommending a liming @ 350 kg ha^{-1}. Nitrogen @ 71 % of POP can be done. Application of phosphorous can be reduced as 25% of POP recommendation and application of potassium as 48% of POP recommendation can be done. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Vechoor

Application of lime @ 850 kg ha^1 is recommended as the mean value for pH recorded a value of 3.59. Application of nitrogen @ 54 % of POP can be done. Application of P as 83% of POP and potassium @ 25 % of POP can be recommended. Secondary nutrients were sufficient in availability. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Thalayazham

Liming @ 600 kg ha^{-1} is recommended as the soils were strongly acidic. Application of nitrogen @ 54 % of POP can be done. Application of phosphorous can be reduced as 25% of POP recommendation and application of potassium as 48% of POP recommendation can be suggested. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Chempu

The soils were moderately acidic with a mean value of 5.8 hence application of lime @ 250 kg ha^{-1} is recommended. Nitrogen @ 78% of POP is recommended. Application of phosphorous can be reduced as 25% of POP recommendation. Application of potassium as 83% of POP is recommendation can be done. Available Ca, Mg and S were sufficient. Application of borax @10 kg ha^{-1}. Deficiency can also be managed by foliar application of borax.

Summary

SUMMARY

The study entitled "Assessment of soil quality in the post-flood scenario of AEU 4 in Kottayam district and generation of GIS maps" was carried out at the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during the period of 2018-2020 with the objective to assess the soil quality in the post flood soils, to work out soil quality index and develop maps on soil characters and quality using GIS techniques.

For this purpose, seventy-five geo-referenced surface soil samples were collected based on a pre-designed questionnaire from 18 panchayats in 4 different blocks (Ettumanoor, Kaduthuruthy, Vaikom and Madapally) of the AEU 4 and various physical, chemical and biological attributes were analysed. The analysed data was used to develop a minimum data set (MDS) by employing principal component analysis (PCA). PCA analysis of 20 attributes resulted in a MDS containing seven attributes. By giving scores and weightage to each component in the MDS, soil quality index (SQI) was worked out. The RSQI values were then computed from the SQI values and the soil was categorized into poor medium and good based on RSQI.

The salient findings observed for the area in the present study is summarised below,

- Major crop in the area was found to be rice. Vegetables, banana, coconut, nutmeg, tapioca were the other crops found in the region.
- Majority of farmers were small to marginal (94.7 per cent) and were following conventional method of nutrient management.
- Bulk density (0.72 to 1.59 Mg m^{-3}) and particle density (1.37 to 2.60 Mg m^{-3}) of the region recorded lower values due to the increased organic matter present.
- Porosity ranged from 14.6 to 73.1 per cent with a mean value of 42.0 per cent.
- Most of the soils were sandy clay loam in texture. Sandy loam, silt loam, clay loam and loam were the other textural class reported in the area.
- Deposition of sand/silt/clay in the study area was not much prominent.
- WHC ranged from 20.6 per cent to 68.8 per cent and soil moisture ranged from 1.11 to 72.3 per cent.

- MWD and percentage water stable aggregates recorded highest at Kallara and Neendoor showing better aggregation of the soils.
- The mean values of pH ranged from 3.48 to 6.47 and most of the area was reported to be acidic.
- Acidity was found to be the major constraints in crop production especially in Kari soils. Farmers were following proper liming practice in the fields.
- EC was found to range from 0.08 to 1.57 dS m^{-1} and salinity effects did not restrict crop growth.
- The percentage of organic carbon was found to be high in all the panchayats which ranged from 0.47 to 12.98 per cent.
- Among the major nutrients, availability of nitrogen was found to be deficient in majority of the places and varied from 75.3 to 1003 kg ha^{-1}, phosphorus was high which ranged from 1.14 to 247 kg ha^{-1} and potassium was medium to high in the AEU (44.8 to 1515 kg ha^{-1})
- Available secondary nutrients were found to be sufficient for the cultivation of crops in most of the areas. Ca content in the soils ranged from 180 to 1820 mg kg^{-1}, Mg content ranged from 24.0 to 1080 mg kg^{-1} and S varied from 0.5 to 1230 mg kg^{-1}.
- Boron was deficient in 78.7 per cent of samples and the minimum mean value for available boron was obtained at Udayanapuram panchayat. The boron content ranged from 0.01 to 1.66 ppm.
- Acid phosphatase activity was found to be higher in Kallara (106 µg of p-nitrophenol g^{-1} soil h^{-1}) and ranged from 2.36 to 157 µg of p-nitrophenol g^{-1} soil h^{-1}.
- PCA analysis carried out with 20 parameters resulted in qualifying of seven parameters in the minimum data set which were organic carbon, available N, P, K, Ca, per cent sand and per cent silt.
- The assessment of soil quality by computing SQI and RSQI categorized most of the samples to be medium to high. The highest RSQI was recorded at Neendoor panchayat.

- Nutrient index calculated were high for organic carbon, low for available nitrogen, and medium for available phosphorus and available potassium.
- LQI categorized majority of the samples (46.7 per cent) to be very low, 38.7 per cent to be low and moderate to high for 4.68 per cent samples

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

by

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ABSTRACT

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ABSTRACT

The study entitled 'Assessment of soil quality in the post-flood scenario of AEU 4 in Kottayam district of Kerala and generation of GIS map' was conducted with the objective to assess the soil quality of post-flood soils, to work out soil quality index (SQI) and to develop GIS maps based on soil characters and quality.

Preliminary survey was conducted in four different blocks of AEU 4 in Kottayam district *viz.* Vaikom, Kaduthuruthy, Ettumanoor and Madapally. Seventy-five geo-referenced surface soil samples were collected from eighteen panchayats selected based on the survey. Paddy, banana, vegetables, coconut and nutmeg were found to be the major crops cultivated in the study area. Ninety-four percentage of farmers in the surveyed area were small and marginal mostly following conventional method of nutrient management.

The soil samples collected from the eighteen panchayats were analysed for various physical, chemical and biological attributes. The physical attributes included bulk density, particle density, porosity, water holding capacity, soil moisture, soil texture, depth of sand/silt/clay deposition, aggregate analysis. Soil texture for majority of the samples (68.8 percent) was sandy clay loam with water holding capacity ranging from 20.6 to 68.8 per cent. Bulk density of 50.7 per cent of samples recorded a value less than 1.2 Mg m^{-3} with a mean value of 1.2 Mg m^{-3}. Particle density of 73.3 per cent samples were less than 2.2 Mg m^{-3}. Depth of sand/silt/clay deposition was not much significant in the study area.

The chemical parameters analysed were pH, EC, organic carbon, available macronutrients and boron (micronutrient). More than 90 per cent of samples were in the acidic range with 6.67 per cent as ultra-acidic, 17.30 per cent as extremely acidic, 20 per cent as very strongly acidic, 14.70 per cent as strongly acidic, 14.6 per cent as moderately acidic and 7.61 as slightly acidic. EC value was less than 1 dS m^{-1} for 89.3 per cent of the samples. Organic carbon was high in 58.7 per cent samples analysed. Availability of nitrogen was found to be low in 78.7 per cent of samples, phosphorus and potassium was high in 54.7 per cent and 40 per cent samples respectively.

Among the secondary nutrients, available calcium was adequate in 88 % of samples while available magnesium was sufficient in 58.7 % samples. Sulphur availability was found to be adequate in 81.3 per cent samples and boron was deficient in 78.7 per cent samples. Activity of acid phosphatase was also analysed as a biological attribute. Activity of 41.3 percentage sample were in the range of 10 to 25 µg p-nitrophenol g^{-1} soil h^{-1}

Nutrient indices were calculated from the analysed data. The analysed data was also used to set up a minimum dataset (MDS) by employing principal component analysis (PCA). Principal component analysis of 20 attributes resulted in a MDS containing seven attributes (organic carbon, available N, P, K, Ca, per cent sand and per cent silt). By giving scores and weightage to each component in the MDS, soil quality index (SQI) was worked out. The relative value for soil quality index (RSQI) was used to categorize the soil into low, medium and good quality. GIS techniques were used to prepare thematic maps of various soil parameters and soil quality indices. Simple correlations were also worked out among various analysed parameters.

Nutrient index was high for organic carbon, low for available nitrogen while it was medium for available phosphorus and potassium.

Compared to the pre flood data (KSPB,2013) soil acidity was increased as there was an increase in percentage samples in ultra-acidic, moderately acidic and strongly acidic range, an increase in organic carbon, available potassium, calcium and magnesium were observed. Even though the availability of phosphorus and sulphur were high in the AEU, percentage of samples in low fertility class was increased compared to pre-flood data. However, availability of boron was decreased and the per cent deficient soil samples considerably increased in the post-flood scenario

The study indicated that RSQI in the majority of soils of AEU 4 of Kottayam district was medium and land quality index was very low to low. The study recommends the site specific adoption of soil management strategies for the control of soil acidity, applications of soil ameliorants, micronutrients such as B for maintaining soil health and quality in the AEU 4 regions of Kerala.

Appendices

APPENDIX I

Proforma of questionnaire used for survey of farmers of flood affected panchayats

1. Name of the panchayat :
2. Name of the farmer :
3. Address :
4. Size of holding :
5. Survey no. :
6. Geographic coordinates of the sampling location :
7. Crops cultivated :
8. Nutrient management practices adopted :
9. Depth of sand/silt/clay deposition after floods :

Appendix II

Area and crop management of sampled locations

Sl. No.	Holding size	Crop	Nutrient management
1	0.15 acre	Banana	INM
2	0.45 acre	Vegetable	INM
3	1.25 acre	Coconut	Conventional
4	2.00 acre	Paddy	Conventional
5	1.25 acre	Paddy and Vegetables like brinjal	Organic
6	1.3 acre	Paddy and Vegetables like brinjal	INM
7	3.0 acre	paddy, vegetables	Conventional
8	1.25 acre	Banana, coconut, Paddy	Conventional
9	1 acre	Paddy	Conventional
10	1 acre	Paddy	Conventional
11	3.5 acre	Paddy	Conventional
12	2 acre	Paddy	Conventional
13	0.15 acre	Coconut	Conventional
14	0.10 acre	Nutmeg	Conventional
15	0.25 acre	Coconut	Conventional
16	2 acre	Paddy	Conventional
17	1 acre	Paddy	Conventional
18	1.5 acre	Paddy	Conventional
19	0.75 acre	Paddy	Conventional
20	1 acre	Paddy	INM
21	0.50 acre	Vegetables, Paddy	Conventional
22	1.25 acre	Paddy	Conventional
23	1 acre	Paddy	INM
24	1.27 acre	banana, vegetables, paddy	Conventional
25	0.30 acre	Nutmeg	Conventional
26	0.66 acre	banana, vegetables, nutmeg, tapioca	INM
27	1.25 acre	Banana, tubers	Conventional
28	0.60 acre	Banana, Coconut, Nutmeg	Conventional
29	1.50 acre	Vegetables, Nutmeg, Tubers	Conventional
30	1.5 acre	Paddy	Conventional
31	0.16 acre	Banana	Conventional
32	0.55 acre	coconut, arecanut, banana	INM
33	1.5 acre	Paddy	INM
34	10 acre	Paddy, Tapioca	INM
35	5.45 acre	Paddy and vegetables	INM
36	0.70 acre	Banana, tapioca, vegetables, coconut, nutmeg	Conventional

(Continued…)

Appendix II continued

Sl. No.	Holding size	Crops	Nutrient management
37	1.5 acre	Paddy	INM
38	1.5 acre	banana, coconut, nutmeg, ginger	INM
39	1.5 acre	Paddy, Banana, Nutmeg, vegetables,	Conventional
40	0.7 acre	Paddy, Banana, coconut, vegetables	Conventional
41	0.30 acre	Coconut, vegetables, Paddy	Conventional
42	0.45 acre	Banana, coconut, pepper	Conventional
43	1.5 acre	Banana, coconut, vegetables	Conventional
44	0.1 acre	tapioca and vegetables	Conventional
45	0.15 acre	tapioca and coconut	Conventional
46	1.34 acre	Vegetables	Conventional
47	0.35 acre	tapioca, tubers	Conventional
48	0.60 acre	Tapioca, banana	Conventional
49	0.15 acre	Vegetables	Conventional
50	1.25 acre	Paddy	Conventional
51	0.75 acre	Banana	Conventional
52	0.75 acre	Paddy	Conventional
53	1.00 acre	Paddy	Conventional
54	0.25 acre	Vegetables, Banana, Turmeric	Organic
55	1.5 acre	Paddy	Conventional
56	1.5 acre	Paddy. Vegetables- Chilli, brinjal	INM
57	0.25 acre	Banana	INM
58	7.5 acre	Nutmeg	INM
59	0.515 acre	Coconut, Arecanut, Nutmeg, tubers	Organic
60	0.65 acre	Coconut, Banana , Nutmeg	Organic
61	0.30 acre	Tapioca	Conventional
62	1.25 acre	Paddy	Conventional
63	1.7 acre	Paddy, banana	Conventional
64	2 acre	Banana	Conventional
65	1 acre	Paddy	Conventional
66	20 acre	Paddy	INM
67	0.45 acre	Paddy	Conventional
68	1 acre	Paddy	Conventional
69	3.5 acre	Paddy, vegetables	Organic
70	0.10 acre	Nutmeg	Conventional
71	0.57 acre	Banana, nutmeg	Conventional
72	0.75 acre	banana, vegetables, nutmeg, tapioca	Conventional
73	1 acre	Nutmeg, Banana	Conventional
74	0.45 acre	Tapioca	Conventional
75	0.75 acre	Banana	Conventional

Appendix III

Results of physical parameters

Sl. No.	BD (Mg m $^{-3}$)	PD (Mg m $^{-3}$)	Porosity (%)	WHC (%)	Soil moisture (%)	MWD (mm)	% Water stable aggregates	% Clay	% Silt	% Sand	Soil texture
1	1.15	2.03	43.35	38.68	6.71	1.43	59.28	31.2	5	63.8	Sandy clay loam
2	1.33	2.25	40.89	37.41	13.78	1.37	59.42	16.2	5	78.8	sandy loam
3	1.15	2.6	55.77	38.68	6.71	1.43	59.28	21.2	5	73.8	Sandy clay loam
4	1.1	1.92	42.71	28.84	35.14	1.43	51.8	16.2	15	68.8	sandy loam
5	1.06	2.1	49.52	49.86	5.66	1.24	58.4	16.2	30	53.8	sandy loam
6	1.09	2	45.5	45.79	25.97	1.2	65.92	16.2	20	63.8	Sandy loam
7	1.33	2.18	38.99	32.84	9.58	2.53	79.94	31.2	30	38.8	clay loam
8	1.19	2.15	44.65	38.11	7.55	2.21	76.36	26.2	10	63.8	Sandy clay loam
9	1.44	2.09	31.1	33.48	11.01	2.53	79.94	21.2	5	73.8	Sandy clay loam
10	1.33	2.24	40.63	32.84	9.58	2.44	83.24	16.2	15	68.8	sandy loam
11	1.03	1.99	48.24	45.99	30.06	1.24	78.52	26.2	20	53.8	Sandy clay loam
12	0.78	1.74	55.17	61.17	34.3	3.14	83.2	26.2	15	58.8	Sandy clay loam
13	0.97	2.17	55.3	45.28	35.1	3.14	83.2	21.2	10	68.8	Sandy clay loam
14	1.03	2.26	54.42	45.99	30.06	1.24	78.52	31.2	10	58.8	Sandy clay loam
15	1.01	1.85	45.41	45.38	27.09	2.84	85.66	31.2	5	63.8	Sandy clay loam
16	1.08	2.3	53.04	41.68	11.47	1.45	87.8	31.2	5	63.8	Sandy clay loam
17	1.01	1.85	45.41	45.38	27.09	2.84	85.66	18.7	7.5	73.8	sandy loam
18	1.08	2.15	49.77	51.85	30.74	1.6	81.16	31.2	5	63.8	Sandy clay loam
19	1.24	2.6	52.31	39.7	8.1	0.87	42.88	26.2	20	53.8	Sandy clay loam
20	0.94	1.96	52.04	53.16	48.55	1.81	72	36.2	5	58.8	sandy clay
21	1.07	2	46.5	52.42	25.67	2.2	84.04	51.2	10	38.8	sandy clay loam
22	1.07	2.01	46.77	52.42	25.67	1.81	72	21.2	15	63.8	Sandy clay loam
23	0.54	2.01	73.13	68.78	120.66	1.81	72	26.2	5	68.8	Sandy clay loam
24	1.21	2.05	40.98	40.4	8.92	2.2	84.04	36.2	20	43.8	clay loam
25	1.28	2.05	37.56	34.21	8.53	2.84	85.66	31.2	15	53.8	Sandy clay loam
26	1.28	2.03	36.95	34.21	8.53	1.23	74.12	21.2	5	73.8	Sandy clay loam
27	1.33	2.34	43.16	36.09	12.73	1.24	78.52	31.2	5	63.8	Sandy clay loam
28	1.33	2.2	39.55	36.09	12.73	1.92	78.2	21.2	20	58.8	Sandy clay loam
29	1.01	2.03	50.25	57.63	16.54	1.92	78.2	46.2	10	43.8	sandy clay
30	1.56	2.08	25	23.72	10.18	1.21	54.76	18.7	7.5	73.8	sandy loam
31	1.56	2.17	28.11	23.72	10.18	1.21	54.76	21.2	10	68.8	Sandy clay loam
32	0.85	2.11	59.72	56.89	64.08	2.35	84.4	26.2	50	23.8	silt loam
33	0.72	1.83	60.66	68.58	72.3	2.86	81.9	26.2	15	58.8	Sandy clay loam
34	0.78	1.78	56.18	66.51	68.1	2.56	77.8	26.2	20	53.8	Sandy clay loam

(Continued…)

Appendix III (continued)

Sl. No.	BD (Mg m $^{-3}$)	PD (Mg m $^{-3}$)	Porosity (%)	WHC (%)	Soil moisture (%)	MWD (mm)	% Water stable aggregates	% Clay	% Silt	% Sand	Soil texture
35	0.86	1.56	44.87	65.61	26.01	2.56	77.8	36.2	30	33.8	clay loam
36	1.46	1.82	19.78	32.81	6.25	1.01	55.36	21.2	5	73.8	Sandy clay loam
37	1.07	2.11	49.29	51.09	11.26	0.76	44.46	16.2	15	68.8	sandy loam
38	1.59	2.44	34.84	20.6	1.11	1.14	58.4	21.2	15	63.8	Sandy clay loam
39	1.07	2.25	52.44	51.09	11.26	1.14	58.4	26.2	40	33.8	Loam
40	1.33	1.8	26.11	36.09	12.73	2.37	70.54	41.2	10	48.8	sandy clay
41	1.15	1.83	37.16	40.77	7.85	2.17	80.48	16.2	20	63.8	sandy loam
42	1.37	2.35	41.7	36	12	0.93	56.06	26.2	35	38.8	Loam
43	1.37	2.49	44.98	36	12	0.93	56.06	26.2	20	53.8	Sandy clay loam
44	1.06	1.88	43.62	53.92	26.2	1.21	76	26.2	5	68.8	Sandy clay loam
45	1.06	2.16	50.93	53.92	26.2	1.21	76.4	36.2	30	33.8	clay loam
46	1.06	2.25	52.89	36	12	0.57	47.9	21.2	5	73.8	Sandy clay loam
47	1.18	2.34	49.57	39.12	16.3	0.57	47.9	16.2	5	78.8	sandy loam
48	1.18	2.38	50.42	41.5	9.52	1.25	62.04	21.2	5	73.8	Sandy clay loam
49	1.18	2.37	50.21	41.5	9.52	1.25	62.04	26.2	5	68.8	Sandy clay loam
50	1.49	2.13	30.05	33.36	5.24	0.41	44.8	16.2	5	78.8	sandy loam
51	1.55	1.91	18.85	27.87	27.87	0.34	38.84	21.2	15	63.8	Sandy clay loam
52	1.49	2.18	31.65	33.36	5.24	0.41	44.8	21.2	5	73.8	Sandy clay loam
53	1.37	2.45	44.08	36.61	5.56	0.39	37.9	26.2	15	58.8	Sandy clay loam
54	1.55	1.98	21.72	27.87	27.87	0.34	38.84	31.2	30	38.8	Clay loam
55	1.37	2.1	34.76	36.61	5.56	0.39	37.9	41.2	10	48.8	sandy loam
56	1.01	1.99	49.25	43.42	42.44	1.19	54.56	31.2	30	38.8	clay loam
57	1.41	2.42	41.74	33.21	17.98	1.55	80.54	16.2	40	43.8	Loam
58	1.41	2.06	31.55	33.21	17.98	1.55	80.54	21.2	15	63.8	Sandy clay loam
59	1.4	2.07	32.37	30.59	14.8	0.95	66.48	23.7	17.5	58.8	Sandy clay loam
60	1.41	2.05	31.22	33.21	17.98	1.19	54.56	21.2	15	63.8	Sandy clay loam
61	1.41	1.95	27.69	33.21	17.98	0.95	66.48	31.2	15	53.8	Sandy clay loam
62	0.82	1.37	40.15	52.32	48.32	0.65	49.76	21.2	5	73.8	Sandy clay loam
63	1.12	1.85	39.46	35.39	33.3	1.02	56.6	16.2	15	68.8	sandy loam
64	1.31	1.93	32.12	41.4	10.16	0.68	61.74	31.2	20	48.8	Sandy clay loam
65	0.92	1.65	44.24	54.45	11.08	0.72	44.72	21.2	15	63.8	Sandy clay loam
66	0.99	1.78	44.38	50.67	18.9	1.02	58.22	26.2	10	63.8	Sandy clay loam
67	0.99	1.44	31.25	50.67	18.9	1.02	58.22	21.2	5	73.8	Sandy clay loam
68	1.28	2.56	50	33.37	12.48	0.54	41.52	16.2	5	78.8	sandy loam
69	1.58	1.85	14.59	26.76	8.39	0.34	41.46	36.2	5	58.8	Sandy clay loam
70	1.28	1.94	34.02	33.37	12.48	0.54	41.52	16.2	10	73.8	Sandy loam
71	1.28	2.16	40.74	33.37	12.48	0.54	41.52	16.2	5	78.8	Sandy loam
72	1.44	2.03	29.06	33.45	19.66	1.34	65.3	26.2	15	58.8	Sandy clay loam
73	1.24	1.89	34.39	39.06	16.88	1.16	63.6	16.2	5	78.8	sandy loam
74	1.24	2.43	48.97	39.06	16.88	1.16	63.6	21.2	15	63.8	Sandy clay loam
75	1.44	2.21	34.84	33.45	19.66	1.34	65.3	21.2	5	73.8	Sandy clay loam

Results of chemical and biological parameters

Appendix III (continued)

Sl. No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (μg pnp g^{-1} h^{-1})
1	4.85	0.44	1.06	151	62.8	56.0	560	84.0	9.00	0.29	25.1
2	5.93	1.21	0.93	151	52.6	448	1420	276	31.0	0.32	45.5
3	7.25	0.68	0.47	1003	16.3	134	1540	108	114	0.37	12.2
4	3.69	1.00	2.81	226	2.28	280	360	420	1000	0.69	23.0
5	5.75	0.93	1.71	201	37.3	291	1820	180	42.5	0.50	49.1
6	5.72	0.21	2.61	263	10.9	123	320	228	33.5	0.59	18.8
7	6.28	0.09	1.61	138	60.8	179	720	84.0	2.50	0.42	29.7
8	7.43	0.88	1.29	627	23.0	269	720	180	35.0	0.49	23.5
9	6.08	0.85	1.50	163	86.3	392	780	192	104	0.30	49.0
10	6.09	0.60	1.70	151	21.7	302	360	168	28.5	0.38	31.4
11	4.54	2.50	5.49	351	5.13	314	540	504	43.5	0.78	13.2
12	4.06	0.30	3.80	289	12.0	381	460	228	51.5	0.28	48.5
13	3.93	1.00	4.07	226	0.57	381	920	720	959	0.46	27.4
14	5.76	0.05	2.09	163	24.2	89.6	500	96.0	5.00	0.58	41.4
15	4.63	0.06	1.92	188	11.3	78.4	300	48.0	6.00	0.38	30.5
16	4.64	0.91	2.39	213	17.3	78.4	260	48.0	5.00	0.44	24.9
17	4.28	1.29	3.99	251	22.8	269	580	336	241	0.75	52.5
18	5.85	0.13	1.79	163	67.0	426	840	228	6.50	0.42	49.6
19	4.39	0.46	1.28	151	7.07	336	540	96.0	93.5	0.41	8.27
20	4.52	0.43	3.48	314	4.22	134	340	180	59.5	0.74	53.0
21	6.36	0.23	2.61	238	68.5	314	1480	192	44.5	0.32	24.9
22	3.85	3.90	7.80	439	1.94	314	900	480	921	0.74	92.5
23	4.04	2.30	6.60	414	1.14	392	360	480	713	0.58	69.7
24	5.15	0.07	1.10	176	79.5	302	440	156	4.50	0.64	13.6
25	5.7	0.07	1.11	151	22.0	146	400	168	2.50	0.36	15.0
26	5.98	0.14	1.71	151	81.3	146	640	108	9.00	0.50	12.9
27	5.74	0.06	2.79	151	69.4	146	680	156	6.50	0.31	17.6
28	5.85	0.06	1.97	151	90.2	168	680	48.0	8.00	0.38	16.2
29	5.8	0.82	1.92	251	45.3	224	920	132	7.00	0.41	35.5
30	6.02	0.07	0.92	100	11.9	448	680	120	3.50	0.50	20.6
31	6.4	0.34	1.77	251	53.1	1512	960	408	17.5	0.29	43.4
32	5.02	0.10	1.76	188	136	44.8	560	120	8.50	0.31	30.0
33	3.35	1.00	11.8	326	1.94	560	1020	984	1182	1.46	120
34	3.11	1.00	8.78	364	1.82	190	440	300	1097	1.04	157

(continued…)

Appendix III (continued)

Sl. No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg pnp g^{-1} h^{-1})
35	3.99	2.70	5.49	339	1.60	336	680	288	794	1.66	39.6
36	5.69	0.09	1.01	125	82.4	190	460	60.0	7.00	0.20	15.1
37	4.96	0.21	1.35	163	7.98	78.4	340	84.0	35.0	0.62	19.4
38	5.96	0.05	0.74	125	26.3	101	320	108	4.50	0.19	8.00
39	5.68	0.09	1.05	138	45.8	190	620	96.0	8.00	0.07	11.9
40	4.95	0.11	0.98	100	10.7	123	420	12.0	0.50	0.46	4.55
41	3.45	1.00	5.28	326	2.28	78.4	1200	204	1230	0.59	7.00
42	5.28	0.09	1.29	138	144	67.2	260	60.0	9.50	0.16	12.2
43	6.26	0.09	1.50	87.8	63.6	101	380	48.0	3.00	0.16	12.8
44	6.58	0.11	1.05	138	56.3	728	500	108	7.50	0.23	8.91
45	4.98	1.25	2.81	276	204.3	1064	1200	156	203	0.36	53.2
46	4.83	1.03	2.97	263	267	549	1340	204	355	0.85	37.9
47	4.96	0.70	2.19	213	274	235	960	60.0	225	0.46	24.5
48	4.97	0.16	1.01	125	158	112	240	60.0	8.50	0.11	7.27
49	5.33	0.13	1.10	113	54.0	202	240	72.0	11.0	0.17	8.09
50	6.52	0.15	1.19	113	157	67.2	900	84.0	10.0	0.55	15.4
51	4.86	0.17	0.84	125	116	89.6	180	48.0	2.50	0.06	2.36
52	6.96	0.40	1.98	201	73.6	280	1380	252	29.5	0.37	13.3
53	5.29	0.12	1.08	75.3	51.5	134	440	168	2.50	0.18	8.36
54	6.46	0.10	0.81	151	15.5	235	840	168	3.50	0.08	4.73
55	4.30	0.98	0.96	113	16.1	112	900	240	387	0.11	6.36
56	5.96	0.19	2.51	289	58.7	112	1280	216	101	0.12	17.5
57	4.92	0.21	2.33	201	12.3	190	440	156	33.0	0.07	10.2
58	5.10	0.26	1.71	188	67.9	582	600	240	36.5	0.11	35.3
59	6.80	0.18	1.05	151	73.5	370	800	252	3.00	0.01	10.6
60	5.16	0.16	0.95	176	15.9	101	340	84.0	31.5	0.18	19.9
61	4.58	0.17	0.84	201	11.9	392	260	72.0	3.50	0.20	2.64
62	3.38	1.00	5.07	263	4.10	549	920	792	965	0.42	12.5
63	3.74	0.48	3.17	289	13.6	269	480	144	18.5	0.36	38.0
64	3.53	0.36	3.99	263	43.2	560	180	24.0	34.5	0.27	56.3
65	3.73	1.00	12.1	301	2.28	571	760	1080	819	0.36	44.5
66	3.71	0.45	3.27	289	22.9	224	420	36.0	67.5	0.22	94.5
67	3.23	1.00	13.0	376	2.74	1030	520	708	1079	0.35	41.5
68	5.30	0.17	1.95	163	66.6	123	440	48.0	4.000	0.15	11.1
69	5.65	0.57	0.47	138	45.1	44.8	660	96.0	79.5	0.06	5.00

(continued…)

Appendix III (continued)

Sl. No.	pH	EC (dS m^{-1})	OC (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{1})	S (mg kg^{-1})	B (mg kg^{-1})	Acid phosphatase (µg pnp g^{-1} h^{-1})
70	5.08	0.14	1.32	138	158	56.0	240	36.0	3.50	0.24	12.8
71	4.72	0.118	1.215	225.79	13	78.4	340	36	6	0.06	19.18
72	5.06	0.22	0.915	163.07	64.98	112	420	132	24.5	0.1	11.91
73	6.26	0.111	1.245	188.16	36.14	100.8	860	132	7.5	0.37	4.82
74	7.68	0.26	2.61	150.53	45.37	280	2420	156	13	0.28	3.27
75	5.3	0.115	1.53	150.53	48.34	257.6	480	168	7	0.01	13.45

SQI and LQI values

Appendix III (continued)

Sl. No.	SQI	RSQI	Rating	SOCS (Mg ha^{-1})	LQI (Kg m^{-2})	Rating
1	255	63.75	Medium	18.4	1.84	very low
2	305	76.25	High	18.6	1.86	very low
3	300	75	High	8.02	0.8	very low
4	235	58.75	Medium	46.3	4.63	Low
5	315	78.75	High	27.2	2.72	very low
6	235	58.75	Medium	42.7	4.27	Low
7	275	68.75	Medium	32	3.2	Low
8	350	87.5	High	23	2.3	very low
9	315	78.75	High	32.4	3.24	Low
10	295	73.75	High	33.8	3.38	Low
11	280	70	Medium	84.8	8.48	medium
12	300	75	High	44.4	4.44	Low
13	255	63.75	Medium	59.1	5.91	Low
14	235	58.75	Medium	32.2	3.22	Low
15	200	50	Medium	29.1	2.91	very low
16	220	55	Medium	38.6	3.86	Low
17	275	68.75	Medium	60.4	6.04	medium
18	315	78.75	High	28.9	2.89	very low
19	255	63.75	Medium	23.7	2.37	very low
20	240	60	Medium	49.1	4.91	Low
21	315	78.75	High	41.9	4.19	Low
22	305	76.25	High	125.2	12.52	high
23	280	70	Medium	53.5	5.35	Low
24	315	78.75	High	19.9	1.99	very low
25	255	63.75	Medium	21.3	2.13	very low
26	275	68.75	Medium	32.8	3.28	Low
27	275	68.75	Medium	55.7	5.57	Low
28	275	68.75	Medium	39.2	3.92	Low
29	295	73.75	High	29.1	2.91	very low
30	265	66.25	Medium	21.4	2.14	very low
31	315	78.75	High	41.4	4.14	Low
32	255	63.75	Medium	22.4	2.24	very low
33	280	70	Medium	127.2	12.72	high
34	240	60	Medium	102.7	10.27	moderate
35	280	70	Medium	70.8	7.08	medium

(continued…)

Appendix III (continued)

Sl. No.	SQI	RSQI	Rating	SOCS (Mg ha^{-1})	LQI (Kg m^{-2})	Rating
36	275	68.75	Medium	22	2.2	very low
37	195	48.75	Low	21.7	2.17	very low
38	235	58.75	Medium	17.5	1.75	very low
39	285	71.25	High	16.9	1.69	very low
40	225	56.25	Medium	19.5	1.95	very low
41	220	55	Medium	91.1	9.11	Moderate
42	250	62.5	Medium	26.5	2.65	very low
43	255	63.75	Medium	30.8	3.08	Low
44	315	78.75	High	16.7	1.67	very low
45	315	78.75	High	44.6	4.46	Low
46	315	78.75	High	47.2	4.72	Low
47	295	73.75	High	38.8	3.88	Low
48	225	56.25	Medium	17.8	1.78	very low
49	265	66.25	Medium	19.4	1.94	very low
50	255	63.75	Medium	26.5	2.65	very low
51	215	53.75	Medium	19.5	1.95	very low
52	295	73.75	High	44.3	4.43	Low
53	275	68.75	Medium	22.2	2.22	very low
54	265	66.25	Medium	18.8	1.88	very low
55	225	56.25	Medium	19.7	1.97	very low
56	280	70	Medium	38	3.8	Low
57	245	61.25	Medium	49.2	4.92	Low
58	315	78.75	High	36.2	3.62	Low
59	315	78.75	High	22.1	2.21	very low
60	225	56.25	Medium	20	2	very low
61	250	62.5	Medium	17.8	1.78	very low
62	255	63.75	Medium	62.4	6.24	Medium
63	280	70	Medium	53.2	5.32	Low
64	285	71.25	High	78.4	7.84	Medium
65	280	70	Medium	166.6	16.66	very high
66	300	75	High	48.6	4.86	Low
67	280	70	Medium	192.7	19.27	very high
68	275	68.75	Medium	37.4	3.74	Low
69	235	58.75	Medium	11	1.1	very low
70	225	56.25	Medium	25.3	2.53	very low
71	215	53.75	Medium	23.3	2.33	very low
72	245	61.25	Medium	19.8	1.98	very low
73	255	63.75	Medium	23.2	2.32	very low
74	295	73.75	High	48.5	4.85	Low
75	295	73.75	High	33	3.3	Low

APPENDIX IV

Panchayat wise soil fertility class for major nutrients as per KAU POP (2016)

Panchayat	pH class	Fertility class as per KAU POP		
		N	P	K
Kumarakom	Strongly acid	6	9	5
Thiruvarp	Moderately acid	8	7	5
Neendoor	Slightly acid	7	9	7
Arpookara	Very strongly acid	9	3	7
Aymanam	Very strongly acid	9	7	6
Kaduthuruthy	Very strongly acid	9	5	7
Thalayolaparambu	Strongly acid	7	9	4
Mulakkulam	Moderately acid	7	9	9
Kallara	Ultra acidic	9	0	9
Velloor	Moderately acid	5	9	3
Vazhapally	Extremely acid	9	1	2
Paippad	Moderately acid	7	9	9
Thrikodithanam	Strongly acid	7	9	6
T.V.Puram	Moderately acid	5	9	3
Udayanapuram	Strongly acid	7	9	7
Vechoor	Extremely acid	9	4	9
Thalayazham	Very strongly acid	9	9	7
Chempu	Moderately acid	6	9	4