ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 16 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS

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By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Assessment of soil quality in the post-flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Assessment of soil quality in the post-flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps"** is a record of research work done independently by Ms. Sreekutty M. R., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, or fellowship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	Per cent
@	At the rate of
BD	Bulk Density
Ca	Calcium
ESRI	Environmental Systems Research Institute
G	Gram
GIS	Geographic information system
GOK	Government of Kerala
GPS	Global positioning system
H	Hour
Ha	Hectare
IDW	Inverse distance weighted
INM	Integrated nutrient management
K	Potassium
Kg	Kilogram
KSBB	Kerala State Biodiversity Board
KSPB	Kerala State Planning Board
LQI	Land quality index
SMC	Soil Moisture content
MDS	Minimum data set
Mg	Magnesium
Mg	Milligram
Mg	Mega gram
MWD	Mean weight diameter
WHC	Water holding capacity
N	Nitrogen
NI	Nutrient index
^{o}C	degree Celsius

LIST OF ABBREVIATIONS AND SYMBOLS USED

P	Phosphorus
PCA	Principle component analysis
PD	Particle density
PNP	Para-nitrophenol
RSQI	Relative soil quality index
S	Sulphur
SQI	Soil quality index
WSA	Water stable aggregates
Zn	Zinc
µg	Microgram

INTRODUCTION

1. INTRODUCTION

Kerala state is one of the Indian States which receive very high rainfall during the monsoon season. In August 2018, the state received unprecedented rainfall causing greater havoc to entire Kerala except Kasargod district. The Government of India had declared it as a Level 3 Calamity, or “calamity of a severe nature”.

As per IMD data, the state received 2346.6 mm of rainfall till the end of August 2018 against an expected value of 1649.5 mm (Anon, 2018). According to the Kerala government, one-sixth of the total population of Kerala had been directly affected by flood and related incidents. The impact of the flood had distorted the life of farmers; the unexpected wave had washed away their cultivations. The devastating flood caused great damage to the soil environment in different ways. Soil fertility and productivity have been disturbed, which needs site specific investigation on different soil fertility parameters. Plant nutrition needs to be relooked into and revised based on the altered soil fertility status, and suitable location specific management practices should be recommended. Several changes may take place when soil is under saturated conditions for an extended period of time affecting biological, chemical and physical soil health. Flooded soil may experience what is called “post-flood syndrome”, similar to the fallow syndrome, where the land is left uncultivated for the entire season.

Heavy rains and flooding had left many farm fields in need of restoration of physico-chemical condition of soil. Waters eroded and exposed the soils, leaving deep gullies, deposition of silt, crop residues, building materials, as well as other types of debris. The flood has resulted in landslides, water stagnation and deposition of sand/ silt/ clay in these areas in different dimensions, which needs urgent attention for restoring and sustaining soil productivity. The soil composition and structure of flood-hit areas had changed, with the potential to affect water infiltration, root growth, soil erosion, biological activities and nutrient cycling. In this context, assessment of soil quality is the basic and urgent step which should be carried out for suggesting short, medium- and long-term strategy for restoring soil productivity in the flood affected areas.

The devastating flood has crippled the State's agriculture production especially the plantation and spice crop which are the backbone of this primary sector. Idukki and Wayanad together account for nearly 62 per cent of the total area under major spices in the state (Preethy *et al*., 2018). Idukki district which lies in the Western Ghats of Kerala, received one of its highest rainfalls starting from the last week of May to middle of August 2018. The district received 3211.1 mm of rainfall against normal value of 1749.1 mm accounting to a percentage increase of 83.58% (CRIS, 2018). All five overflow gates of the Idukki Dam were opened at the same time. The district has seen worst scenario during floods and landslides in 2018.

Almost all the panchayats in the district reported landslides which generated debris flows, rock falls, rock slides and mud slips. The rain water which entered the soil increased the weight of the unconsolidated soil materials causing instability and this moves downward under the influence of gravity causing great damage to the entire course of its run. In this situation surface soils removed, and the sub soils got exposed.

The heavy rains which were received in the high ranges and different catchment areas supplied flood water to Periyar river. The water in this river and its tributaries gathered different kinds of materials. Sedimentation brought about by the floods, across different panchayaths reported damages to many annual crops. The natural compaction due to heavy sedimentation during the flood might have reduced the aeration capacity of the soil and extended moisture availability in soil led to rhizosphere issues to many crops, necessitating biological and chemical interventions. The standing flood water carrying suspended clay and silt particles on the land had virtually reduced the aeration and infiltration capacity of the soils at many locations, which may affect the ground water recharge in future.

Studies of changes in soil characteristics under experimental treatments typically generate large data sets from a suite of measured parameters. But it is difficult to judge quantitatively whether the soil as a whole has improved, deteriorated, or stayed the same, since integration of the analytical results remains subjective. The evaluation of soil quality could be helpful to assess the level of disturbance in agricultural soils and useful in deciding the best alternative to have an adequate crop production preserving the soil quality (Karlen *et al*., 1997). Thus, a valid soil quality index would help interpret data of soil test values and show whether management and land use are having the desired results for productivity, environmental protection, and health.

Spatial variations of soil nutrient status, as a result of flooding, have been observed across the fields. Hence, the need to separate the fields using geographical information systems (GIS) for effective soil and crop management in order to obtain optimum productivity. The use of GIS will help farmers to overcome over- or under- application of fertilizers.

The devastating flood has altered the surface soil characteristic and soil fertility there by affecting the productivity. In this flood, highlands and midlands have been bereft of topsoil along with subsoil. So, it is really important to support the farmers by providing suitable management aspects in the post-flood scenario. The changes need to be obviously identified by analyzing the physico-chemical and biological soil quality parameters and make them aware about the current status and suggest measures to tackle the problem, thereby ensuring effective implementation of post-flood management activities in agriculture sector. A detailed study on soil quality of post-flood soils of various agro ecological units covering predominant cropping systems prevailing in those Agro Ecological Units (AEU's) will help in formulating sustainable crop management strategies in these floods affected areas.

With this background, a study entitled "Assessment of soil quality in the post-flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps" was undertaken with the following objectives:

- To assess soil quality of post-flood soils of AEU 16 in Idukki district of Kerala.
- To develop maps on soil characters and quality using GIS techniques
- To understand the variations in soil quality using different index approaches in post-flood soils.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Assessment of soil quality in the post- flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps was conducted to help formulation of management strategies for the farmers of the region. In this connection a glance through the works already done with respect to soil physico-chemical characteristics of the region, evaluation of soil quality parameters in post-flood affected areas, GIS map generation based on the quality parameters aiding the modified crop management will help evolving a better management strategy.

AEU 16: Kumily High Hills

The Kumily high hills agro-ecological unit is delineated to represent low-rainfall parts of the high hills zone. It spreads over 3 blocks (Azhutha, Kattappana and Nedumkandam) in Idukki district. The unit differs from southern high hills not only in lower rainfall, however additionally the tremendous incidence of very deep, non-gravelly clay soils. The climate is tropical humid monsoon with mean annual temperature of 22.5° C and mean annual rainfall of 1809 mm. Probability of two consecutive weeks receiving greater than 20 mm rainfall is high from May to mid-November. Length of growing duration for annual crops is forty weeks, while the length of dry period is frequently restrained to three months (KAU, 2016).

The soils of most parts of the AEU are very deep, well drained, acid, non-gravelly, low activity clay and are rich in organic matter. The highland valleys in the unit are very similar, except for impeded drainage conditions. Soil moisture stress is experienced for 3 to 4 months during summer periods. The major land use pattern includes plantations of cardamom, tea, coffee, and pepper. Forest cover is also substantial (KAU, 2016).

2.1.1. Characteristics of Idukki soils

The hilly areas of Western ghats are dominated by subsistence agrarian economy. The region is highly vulnerable to accelerated soil erosion, landslides, loss of soil fertility as well as productivity and rapid loss of habitat and genetic diversity (Anup, 2004). On steep sites, the agricultural activity and the associated removal of deep-rooted permanent vegetation has increased the chances of landslide hazard. As slope increases, the percentage of land affected by landslides, increased sharply on land used for crop production (Perotto-Baldiviezo *et al.*, 2004).

A soil fertility survey in potential cardamom growing tracts in Idukki district of Kerala and Coorg district in Karnataka by Sadanandan *et al.* (2002) showed that majority of the soils are Mollisols followed by Alfisols. They are, derived mainly from schists, and granites. These are acidic, which vary from clay loam to sandy clay loam in texture, with 33% of samples low in K, while 28% medium and 39% high. Kaolinitic type of clay fraction is predominant and there is very little K fixation. The soils are low in base exchange capacity and available K. The soils derived from forest litters and addition of organic matter applied has rendered a high organic matter status, favouring the retention of soil moisture (Sadanandan *et al.*, 2002).

The unprecedented floods during the monsoon season in 2018 have brought a great havoc in the district. Extreme rainfall at 1-15 days duration in August 2018 in the catchments upstream of the three major reservoirs of Idukki, Kakki, and Periyar had the return period of more than 500 years (Mishra *et al*., 2018). The disturbances caused by floods and landslides have brought temporal and spatial heterogeneity in the structure and dynamics of natural communities and ecosystems.

A study conducted by Sreepriya and Balasubramanian (2020), found that the damage to agricultural sector by the flood, accounted for 65.19 per cent of the total damage cost of households. Damage to the agricultural sector was higher due to the loss of entire crop area due to landslides, with cropping pattern including mainly perennial and plantation crops. These catastrophic events, particularly landslides, flooding and erosion have an important role in distribution of nutrients.

2.2. Effect of flooding on soil

2.2.1. Effect of flooding on physical attributes

A study conducted by De Campos *et al*. (2009) in the Midwestern United States examined the effects of harsh wet conditions on both cultivated and uncultivated soils. During the wet season in the U.S. Midwest, upland soils are often under water for days or weeks, causing oxygen depletion, or reducing conditions, which may in turn affect the chemistry of the soil-water system and, thereby, soil aggregation. Loss of soil aggregation reduces soil quality and crop production. The research revealed that the aggregate stability of upland soils decreased under waterlogged conditions. The decrease in aggregate stability reached approximately 20 per cent during a 14-day ponding period. Variations in redox sensitive elements, alkaline metals, and dissolved organic carbon under reduced conditions contributed to the decrease in aggregate stability. Overall, the aggregate stability of cultivated soils was found to be more affected by the flooded conditions than that of uncultivated soils which indicates that the management system plays an important role in the stability of aggregates.

Water logging affects net solar radiation absorbed, heat capacity, soil temperature and heat fluxes in and out of the soil. Lower albedo values of soils are observed as increase in water content darkens the soil. Flooding destroys soil structure due to disruption of aggregates and alters soil consistency (Ponnamperuma, 1984). Gaseous exchange between soil and air is inhibited by submergence. An anaerobic condition is created during flooding by the microbes and flora utilising all the available oxygen. A wide range of toxic compounds are formed in water logged soils that inhibit plant metabolism (Kozlowski, 1984). Accumulation of carbon dioxide, methane, nitrogen and hydrogen in soils occurs due to drastic reduction of gaseous exchange.

In case of Idukki, soil aggregation which affected agriculture by decreasing soil quality and crop production after the flood was found to be weak and a change in texture and organic matter content led to changes in the water holding capacity. Samples collected from the flood affected areas of Idukki for assessing the water holding capacity, recorded wide variations indirectly reflecting differences in the soil separates that had accumulated (KSBB, 2019)

2.2.2. Effects of flooding on chemical attributes

The changes in chemical attributes of soils may happen either due to washing off or deposition of nutrients. Flood deposits organic materials, minerals, and essential nutrients from rivers and oceans into land which makes the soil richer, fertile and productive (Stephen, 1993). A study conducted by Unger *et al*. (2009) found that 5-week flood treatments affected soil inorganic-N in such a way that it decreased NO_3-N and increase in soil NH_4-N increased in soil. Njoku *et al*. (2014) showed that soil properties such as total porosity, moisture content, pH, and organic carbon were higher in a soil after flooding compared to the pre-flood scenario. According to Ubuoh *et al*. (2016), losses of soil nitrogen can be substantial, nitrate nitrogen can be lost by leaching down and made unavailable for crops. While leaching occurs fast on coarse textured sandy soils, it is a slower process on loam and clay soils due to slower water movement.

The gaseous loss of nitrogen by denitrification occurs when soil microorganisms reduce nitrate under waterlogged conditions, leading to loss of nitrogen gas. In addition, soil microorganisms are not very effective at decomposing crop residues and organic matter when the soil is saturated, hindering the release of nitrogen (Adriano, 2001).

The main effect in the sequence of waterlogging-induced processes is a reduction of the oxygen concentration of the soil (Ernst, 1990). Sensor data revealed a decrease in redox potentials and dissolved oxygen under flooded conditions (Unger *et al.*, 2009). According to the comparative values of the soil samples, the contents of organic carbon, humus, total nitrogen, available phosphorus and available potassium of the sample after flood are higher than that of the pre-flood scenario (Khaing *et al*., 2019).

2.2.2.1. Change in pH after flooding

When an acid soil is kept under flooded condition, there is an increase in pH, whereas in case of alkaline soils, the pH decreases. Reduction of iron from Fe III to Fe II is the cause of increase in pH. Accumulation of CO_2 is the cause of decrease in pH of calcareous soils and the check on the pH rise of acid soils (Ponnamperuma, 1984).

The pH of the soil samples representing different terrains of Idukki showed a marginal increase in the pH compared to its corresponding samples in the pre flood situation. This variation must have occurred because of the sedimentation of some basic cations at the surface of the sampling points. The meagre presence of organic deposits or debris at the surface or its slow degradation must have prevented the production of organic acids and thereby prevented a build-up of acidity at the site (KSBB, 2019).

2.2.2.2. Change in electrical conductivity after flooding

Flooding air-dry soils causes direct and indirect electrochemical changes. One direct and almost spontaneous change is the dilution of the soil solution. This increases pH, decreases electrical conductance, and alters the diffuse double layer of colloidal particles (Ponnamperuma, 1984).

In spite of the heavy rains and deposits of soil sediments at many sampling points, the electrolytic conductivity could not register any appreciable enhancement in value compared to the pre flood situations, indicating the absence of soluble ions at the soil surface. Electrical conductivity values (0.15 to 0.98 $dS\ m^{-1}$) were found to be suitable for crop production (KSBB, 2019).

2.2.2.3. Change in organic carbon after flooding

The soil samples representing the highland terrains maintained an enhancement in the organic carbon status. The enhancement or decrease in the organic carbon in the different terrains must be either due to accumulation or removal of organic sources in surface soils under the influence of flood water. Under the influence of the inclement weather experienced in the area, the relatively higher amount of organic matter observed in mountainous terrain and highland terrain must also be due to the slow mineralisation of organic sources. Organic carbon content increased in the mountainous, highland and upland locations (KSBB, 2019).

2.2.2.4. Change in available potassium after flooding

The increase in the available K status observed at the different sampling sites in the highland and upland terrains must be due to the accumulation of K bearing minerals or exposure of K bearing minerals from below (KSBB, 2019).

2.2.2.5. Change in available Sulphur after flooding

The landslide areas of Idukki district maintained fairly good variations between samples as far as the sulphate content is considered. All the samples come under the safe limit as far as the risk classification is considered and offer no threat on account of the sulphate content in soils (KSBB, 2019).

2.2.3. Effect of flooding on biological attributes

Flooding is likely to affect soil enzyme activities by changing nutrient availability and oxygen concentrations as well as due to shifting of microbial population composition (Burns and Ryder, 2001). Soil inundation also results in oxygen depletion, fostering anaerobic conditions and microorganisms able to survive these conditions (Unger *et al*., 2009). Such changes in soil abiotic conditions can alter soil microbial population composition (Wagner *et al*., 2015).

A study conducted by Burns and Ryder (2001) showed strong temporal peaks in enzyme activity from riverbanks, peaking during first week following flooding and with a general decline by third week. Mace *et al*. (2016) reported differences of the activities of phenol oxidase, peroxidase and 1,4-β-N-acetyl glucosaminidase were more pronounced in more heavily flooded sites. Further, plant species richness significantly enhanced changes in 1,4-β-N-acetyl glucosaminidase and phosphatase activity.

2.3. Soil quality

Soil serves as a medium for crop growth by providing physical support, water, essential nutrients, and oxygen for roots. The suitability of soil for sustaining crop growth and biological activity is a function of many physical (porosity, water-holding capacity, structure, and tilth) and chemical (nutrient supplying ability, pH, salt content, etc.). Much like air or water, the quality of soil has a significant effect on the health and productivity of a given ecosystem. Karlen *et al.* (1997) defined soil quality as "the capacity of specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation".

Integration of basic physical, chemical, and biological indicators are required for evaluating the diverse effects of climate and management on soil function. Ecosystem services influenced by many soil processes, are in turn affected by soil threats. The EU Soil Thematic Strategy identified the important threats to soil quality in Europe as soil erosion, organic matter decline, contamination, sealing, compaction, soil biodiversity loss, salinization, flooding and landslides (Montanarella, 2003). Soil threats have been emphasized in order to inform risk assessment exercises indicating the geographical areas where soil functioning is potentially hampered (Van Beek *et al*., 2010).

2.3.1. Importance of soil quality and its Assessment

Soil quality is important for two reasons. First, unscientific use of soil can damage itself and the ecosystem; therefore, the management of land to the soil's capability need to be matched. Second, there should be a baseline understanding about soil quality so that we can identify alterations as they occur. Therefore, the ultimate purpose of assessing soil quality is to protect and improve long-term agricultural productivity, water quality, and habitats of all life forms. Individual soil properties or processes may not provide a proper indication of soil quality and integrated soil quality indicators based on a combination of soil properties can better reflect the status of soil quality than individual parameters. The change in soil quality with time indicate whether the soil condition is sustainable or not (Arshad and Martin, 2002; Doran, 2002).

Soil quality cannot be measured directly however; it can be inferred by measuring physiochemical and biological properties of soil that serve as quality indicator (Brejda *et al*., 2000, Diack and Stott, 2001). Therefore, an integrated 'soil quality index' based on the weighted contribution of individual soil property to maintain the soil quality may serve as a better indicator of soil quality for different land uses.

Soil quality is generally assessed by two approaches. The first one is a comparative method in which soil quality of a given land use or management is evaluated in a given period. The second one is a dynamic approach where the evaluation of soil quality is done using temporal data (Shukla *et al*. 2006).

Karlen *et al.* (1997) proposed a conceptual framework for soil quality evaluation and then Andrews *et al.* (2004) developed a quantitative formula, and they suggested that the monitoring of soil quality is done by focusing on soil functions. Nowadays, soil quality is used as a method to evaluate land-use systems at various scales from regional to the national level (Mukherjee and Lal 2014; Vasu *et al*., 2016).

2.3.2. Soil quality indicators

2.3.2.1. Physical Indicators

Physical parameters such as soil texture, structure, hydraulic conductivity, infiltration, porosity, bulk density, and aggregate stability are used as physical soil quality indicators. They are used to assess the physical quality of soil and linked with seedling emergence, root growth, water movement, water holding capacity, penetration resistance, etc. Physical attributes play an important role in determining the soil erodibility and soil- plant- water-atmosphere relationships (More, 2010).

Dexter (2004) proposed the "S-value" as an indicator for the measurement of soil physical quality. The "S-value" is related to hydraulic conductivity, compaction, water content, penetration resistance, and aggregate stability (Dexter and Czyz, 2007).

2.3.2.2. Chemical Indicators

Important soil chemical processes are ionic diffusion, leaching, acidification, alkalinization, salinization, mineralization, etc. Maintaining a favourable nutrient content is critical to the chemical quality of soil. Both long-term use of subsistence agricultural practices without proper fertilization and heavy usage of chemical fertilizers in intensive high productive agricultural systems results in rapid decline in chemical quality of soil. The chemical indicators of soil quality are pH, EC, salinity, sodicity, organic carbon, nitrogen reactions, phosphorus concentration, cation exchange capacity (CEC), and heavy metal concentrations. Among the chemical indicators, P concentration, cation exchange capacity, available sodium and magnesium, and hydraulic conductivity (which are interrelated) are considered relevant in rainfed agriculture production systems, and they are also used to evaluate chemical and physical degradation (Vasu *et al*., 2016; Vasu *et al*., 2018). Assessment as soil pH and available P indicate most of the nutrient-related transformations in soil, they are the most used chemical indicators in soil quality.

2.3.2.3. Biological Indicators

The microorganisms play a vital role in organic matter decomposition and recycling of nutrients. The microbes have the ability to alleviate the consequences of disturbances on soil ecosystem services, due to their resistance, resilience, and/or functional redundancy (Allison and Martiny, 2008).

The soil microbes respond rapidly to changes in soil and indicate the processes altering the quality of soil. The high sensitivity of microbes to the changes in the soil processes is beneficial as they can be used to monitor the short-term changes in the soil effectively (De La Rosa, 2005). Population of micro- and macro organisms, earthworms, nematodes, termites, and their actions are most important indicators of soil quality.

The microbial biomass is an unavoidable part of the active ingredient in soil responsible or nutrient circulation and degradation of organic pollutants (Stenberg *et al*., 1998). Respiration rate and microbial biomass carbon (MBC) are used to measure microbial activity and microbial decomposition of organic matter in the soil. Enzymes in soil are produced by microbes, plant roots, and fauna, and they have a very important role in nutrient cycling. Enzymes such as dehydrogenase, urease, phosphatases, and glucosidase serve as a measure of nutrient mineralization in soil, and they can provide an early warning to the potential threats to soil quality (Comino *et al*., 2018). Recent studies also used enzyme activity to evaluate the effect of tillage practices on soil quality (Raiesi and Kabiri 2016).

2.4. Concept of Minimum Data Set

Soil quality is a way of examining the soil as a whole and not just its parts. Hence, the quantitative determination of soil quality is a cumbersome process. Moreover, analyzing all the soil properties increases the cost of soil quality evaluation especially in large-scale attempts. Data sets are the tools necessary to provide an idea of soil quality. The strategy of data sets is dynamic and flexible. They become the means where interest groups (e.g., scientists) or society can relate to, utilize, or assess soil for a specific reason or purpose. The development of minimum data sets involves the selection of a small subset of attributes. Many of the attributes are related to each other and may be used to estimate other attributes through the use of functional relationships called pedotransfer functions (Bouma 1989; Larson and Pierce, 1991). A large number of pedotransfer functions have been developed from information in a specific area or from data on different soil types.

Researchers developed different methods to identify minimum soil data set (MDS) as indicators to determine soil quality. Principal component analysis (PCA) (Andrews and Carroll 2001), expert opinion (Andrews *et al*. 2002), factor analysis (Shukla *et al*.

2006) and pedotransfer functions, linear and multiple regression, decision trees (Moncada *et al*. 2014), are some of the commonly used methods.

Basic soil quality indicators should also be sensitive to changes in management or climate. If indicators of soil quality are insensitive to variations in management and climate, they will be of little use in monitoring changes in soil quality and proposing management changes to increase soil quality.

2.5. Soil Quality Index

Development of soil quality index is one way to integrate information obtained from MDS measurements. Such an index could be used to monitor and predict the effects of farming systems and management strategies on soil quality, or could provide early signs of soil degradation (Parr *et al*., 1992). Granatstein and Bezdicek (1992) suggested that soil quality index is very important as it reflects both the general potential for human use and unique biophysical conditions of a specific location.

Soil quality indexing involves three main steps: (1) choosing appropriate indicators for a minimum data set (MDS); (2) transforming indicator scores; and (3) integrating the indicator scores into the index. The concept of the minimum data set of soil quality indicators that reflect sustainable management goals is widely accepted but has relied primarily on expert opinion (EO) to select MDS components (Larson and Pierce, 1991; Doran and Parkin, 1994; Karlen *et al*., 1996).

The physiological rhizosphere studies of Bachmann and Kinzel (1992) used various methods like principle component analysis, multiple correlation, factor analysis, cluster analysis and star plots to select characteristics for their diagnostic index. Bentham *et al.* (1992) used principal component analysis and other statistical clustering techniques to choose variables best representing the progress of soil restoration efforts. To compare agroecosystem management practices, numerous SQIs have been developed varying widely in complexity and need for expert knowledge.

Karlen and Stott (1994) developed a framework for evaluating soil quality using multi-objective analysis principles of systems engineering. All indicators affecting a particular soil function are grouped together and assigned a relative weight based on importance. After scoring each indicator, the value is multiplied by the appropriate weight, and ·an overall soil quality rating is evaluated by summing the weighted score for each soil function.

2.5.1. Methods to calculate SQI

Two methods used to calculate SQI are additive and weighted index methods. Karlen *et al.* (1998) used weighted indices based on expert opinion to assess land coming out of the conservation reserve program (CRP). A simple additive index was used by Andrews and Carroll (2001), to compare organic amendments to fescue pastures.

Additive method involves the calculation of index by summing up the transformed scores of the indicators from MDS. In weighted method, index is evaluated by the following procedure: the transformed indicator data is the assigned weightage based on the variability explained by the principal components. The reaction of variability accounted by each principal component as a part of total variability is used as weight factor selected from the respective principal components (Ray *et al*., 2014). The transformed scores are multiplied by the weight factors and then summed to derive SQI. In expert opinion method, the weight factor is determined by the relative importance of selected indicators influencing changes in soil function.

2.6. Land quality

The need for development of a land quality index (LQI) with reference to type of land use was emphasized by Pieri (1995) and Karlen *et al*. (1997). However, successful application of land quality indicators depends on the definition of indicators based on scale level, complexity and transferability, the careful selection and the integrated presentation of indicator values in the research (Hoosbeek and Bouma, 1998).

Dumanski and Pieri (2000) explained that indicators of land quality are being developed to co-ordinate actions on land related issues, such as land degradation and that land quality refers to the condition of land relative to the requirement of land use, including crop production, forestry, conservation and environmental management.

In an assessment of land quality of forest plantations in Kerala by Balagopalan and Jose (1995), it was reported that the balance in natural climax forest is disturbed when natural forest is removed and soil is prone to environmental factors. Soil erosion is a major problem because of the undulating topography.

Surface crusting is an important form of soil degradation with a potentially strong impact on land quality as it retards the seed germination and water infiltration (Batjes, 1996). Assessment and monitoring of land quality in southern states of India was done by Natarajan *et al*. (2005) and drawn the findings that organic matter, bulk density and yield data were some of the indicators that could be used to monitor soil quality in the region.

2.7. Nutrient index

Nutrient index value (NIV) is the measure of nutrient supplying capacity of soil to plants (Singh *et al*., 2016). In order to compare the levels of soil fertility of one area with those of another, it was important to obtain a single value for each nutrient.

The nutrient index approach introduced by Parker *et al*. (1951) has been adopted and alterations has been made by several researchers. This index is used to assess the soil fertility status based on the samples in each of the three classes, i.e., low, medium and high. Nutrient index methods and fertility indicators are used for evaluating the soil fertility status. The fertility status of soils of several micro-watersheds in Karnataka has been mapped and documentation of nutrient status of these areas is done (Vishwanath *et al*., 2008; Pulakeshi *et al*., 2012; Vidyavathi, 2012). Ravikumar (2013) evaluated the nutrient index of soils using organic carbon, available P and available K concentrations as an indication of soil fertility in Varahi River basin, India.

In order to compare the levels of soil fertility of one area with that of another, it is necessary to obtain a single value for each nutrient. A detailed soil survey was undertaken in Bogur micro-watershed in the state of Karnataka with the aim of evaluating the fertility status of soils using nutrient index approach (Denis *et al.*, 2016).

2.8. Use of GPS, GIS and remote sensing for soil sample collection and data interpretation

The Geo-statistical approach is useful in mapping of soils and soil properties, study of pedogenic factors, nutrient variation and can be independently managed over distances and delineate size and uniformity of soil management units (Vieira *et al*., 1981). Geographic Information System (GIS) is a computerized spatial information system capable of supplying data or information for various levels of planning (Dixit *et al.*, 2005).

Lee *et al.* (1988) reported that thematic data could be successfully used for broad level soil classification with distinct differences in soil properties like surface texture, soil wetness and organic matter content. Spatial variability maps for nutrient status of soils in the coastal agro ecosystem of Karnataka using GIS techniques was prepared by Dasog *et al*. (2006) and observed low to medium available nitrogen, low to medium available phosphorous and low available potassium in the soil.

A study was undertaken by Jagdish (2017) to assess the soil fertility status of composite soils collected across Nagari mandal in Chittoor district of Andhra Pradesh, delineate the spatial variability of soil fertility status using Arc GIS map software in order to suggest fertilizer recommendations. The GPS data at each sampling site was collected. Integration of GIS with various models was highly useful in generating the soil suitability assessment, fertilizer recommendation maps, assessment of soil quality and preparation of customized fertilizer formulation.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A study entitled "Assessment of soil quality in the post- flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2018-2020.

The investigation includes:

1. Survey, collection and characterization of soil
2. Setting up of a Minimum Data Set (MDS) for assessment of soil quality
3. Formulation of soil quality index (SQI), land quality index (LQI) and nutrient index (NI)
4. Generation of geographical information system (GIS) maps
5. Statistical analysis of data

3.1. Survey, collection and characterization of soil

3.1.1. Details of location of sampling

Soil samples were collected from AEU 16, which represents the Kumily high hills of Idukki district in Kerala. Thirteen panchayaths distributed in Peerumedu and Udumbanchola taluks of Idukki district constitute this unit. The unit covers an area of 1,50,984 ha (3.1%) in the state (KAU, 2016). The eight panchayaths that were affected by flood were identified by the data and support provided by the agricultural officers of all krishibhavans in the AEU. The panchayaths included Rajakumari, Santhanpara, Senapathi, Udumbanchola, Pampadumpara, Karunapuram, Nedumkandam and Vandiperiyar. Representative samples were collected from these panchayaths.

3.1.2. Collection of soil samples

A survey was conducted from the sampling locations based on predesigned questionnaire (Appendix I). These include the basic details of the farmer and land holding, crops grown, land use, nutrient management practices followed, notable changes in the soil as well as crops at the time of flooding.

Seventy-six representative geo referenced surface soil samples were collected from the flood affected locations during April 2019 for analysing physical, chemical and biological attributes. Core samples were also taken from the surface soils for analysing physical attributes. Representative samples were collected from a depth of 0-20 cm from each sampling site. The samples were immediately sealed in plastic covers and the geographical coordinates of the locations were recorded using GPS. Soil samples were air dried and the lumps were broken. The crushed aggregate particles were passed through a 2 mm sieve and for determining organic carbon content, a 0.5 mm sieve was used. The substrate used for the enzyme assay of acid phosphatase was p-nitrophenyl phosphate followed by incubation for one hour at 37 °C.

Table 1. Details of sampling locations from AEU 16 in Idukki district

SL. No.	Panchayath	No. of samples	Sampling points	Latitude (°N)	Longitude (°E)
1	Rajakumari	18	1	9.974385	77.15938
			2	9.9914	77.174752
			3	10.002525	77.180012
			4	9.983364	77.160811
			5	10.010597	77.188429
			6	10.015404	77.173063
			7	10.001426	77.164345
			8	10.007893	77.166502
			9	9.992423	77.162291
			10	9.998097	77.147069
			11	9.991043	77.145892
			12	9.972711	77.145246
			13	9.983609	77.14648
			14	9.977327	77.130859
			15	9.963705	77.171632
			16	9.967121	77.131281
			17	9.966549	77.154668
			18	9.959071	77.187512
2	Santhanpara	14	19	9.967201	77.252749
			20	9.971893	77.197653
			21	9.977938	77.227806

Table 1. continued

SL. No.	Panchayath	No. of samples	Sampling points	Latitude (°N)	Longitude (°E)
			22	9.926453	77.218454
			23	9.946971	77.197724
			24	9.940703	77.218044
			25	9.99006	77.23235
			26	9.954109	77.236226
			27	9.993828	77.200474
			28	9.961157	77.221921
			29	9.984511	77.192348
			30	9.985218	77.249427
			31	10.008596	77.243498
			32	10.002812	77.212683
3	Senapathi	6	33	9.952203	77.131459
			34	9.938129	77.142152
			35	9.941475	77.122527
			36	9.941464	77.169895
			37	9.929777	77.163855
			38	9.94951	77.150975
4	Udumbanchola	8	39	9.921749	77.191062
			40	9.906602	77.193921
			41	9.889743	77.194688
			42	9.87286	77.192971
			43	9.904418	77.172235
			44	9.918544	77.110963
			45	9.908455	77.135484
			46	9.893817	77.145693
5	Karunapuram	2	47	9.798212	77.206819
			48	9.761561	77.201017
6	Pampadumpara	14	49	9.802896	77.181
			50	9.795222	77.174391
			51	9.81338	77.167002
			52	9.795963	77.153488
			53	9.805097	77.156134
			54	9.806002	77.135644
			55	9.814916	77.147554
			56	9.772642	77.167317
			57	9.784263	77.163625
			58	9.766221	77.169098
			59	9.784563	77.143461
			60	9.761474	77.155046

Table 1. continued

SL. No.	Panchayath	No. of samples	Sampling points	Latitude (°N)	Longitude (°E)
			62	9.772459	77.153122
7	Nedumkandam	3	63	9.869411	77.122414
			64	9.848113	77.160194
			65	9.837394	77.199278
8	Vandiperiyar	11	66	9.574913	77.079295
			67	9.556406	77.118023
			68	9.543727	77.077282
			69	9.601883	77.068289
			70	9.531349	77.104886
			71	9.559754	77.066936
			72	9.545606	77.136689
			73	9.545613	77.103315
			74	9.558848	77.090627
			75	9.525769	77.083227
			76	9.586962	77.077841

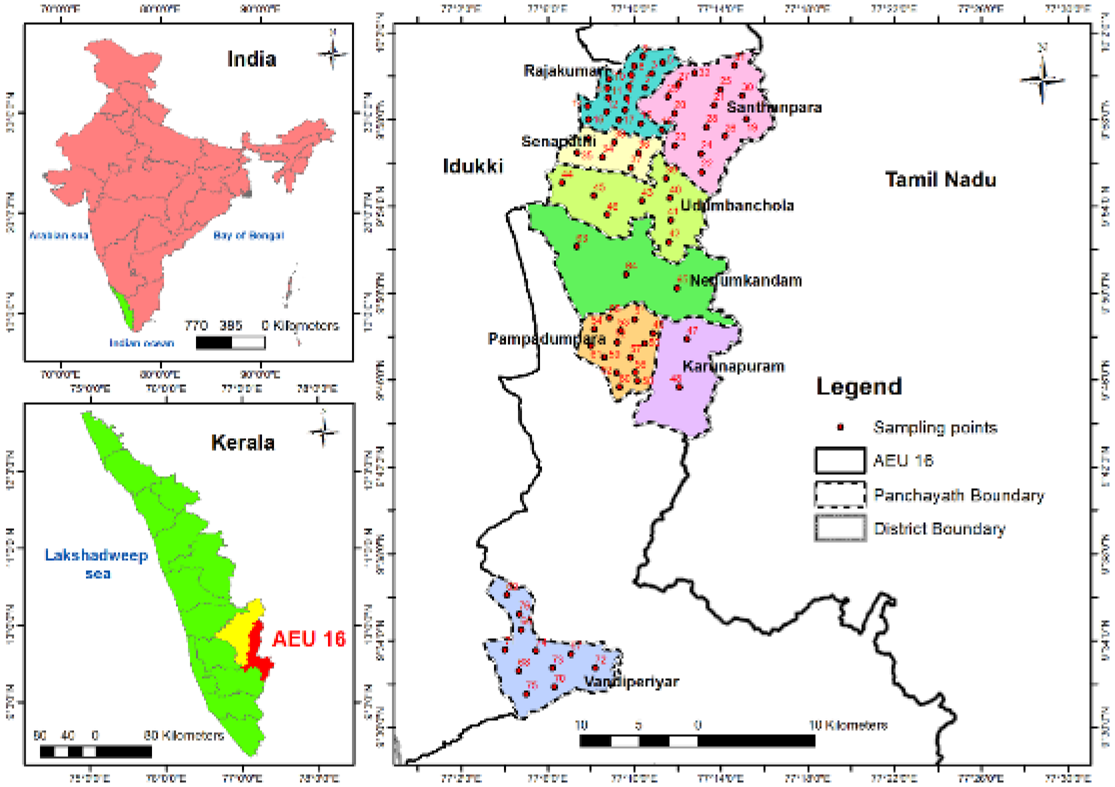

Fig 1. Location map of samples in AEU 16 of Idukki district

Plate. 1. Surface soil sample collection.

Plate. 2. Soil sample collection using core.

3.1.3. Weather data of the area

The weather data of the area during May 2018 to May 2019, average monthly rainfall and number of rainy days of ten years from 2008 to 2017 were collected from CRS, Pampadumpara. The monthly mean maximum and minimum temperature, relative humidity, rainfall and number of rainy days are represented in Fig 2.

The deviation in rainfall (mm) and temperature (°C) during 2018 compared with the average value for 2008 to 2017 is represented in Table 2.

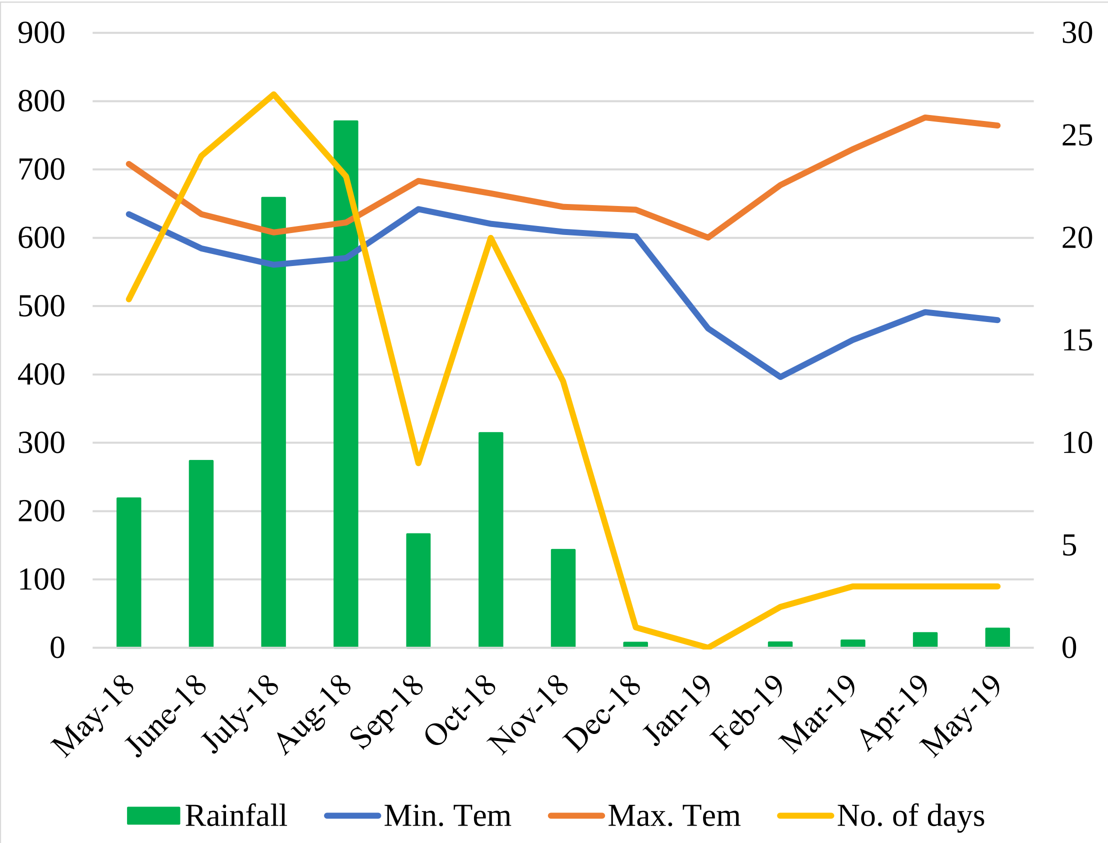

Fig 2. Monthly mean of weather parameters in Idukki district (May 2018 to May 2019).

Table 2. Deviation in rainfall during 2018 from the average monthly rainfall over a period of 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	15.60	2.000	-13.60	1.20	1.0	-0.20
February	13.04	24.00	+10.96	1.10	3.0	+1.90
March	50.48	83.00	+32.52	3.50	5.0	+1.50
April	100.3	69.60	-30.67	6.40	8.0	+1.60
May	95.77	218.7	+122.9	6.30	17	+10.7
June	262.2	273.2	+11.01	18.2	24	+5.80
July	323.6	658.6	+335.0	23.1	27	+3.90
August	281.1	770.5	+489.4	20.1	23	+2.90
September	178.3	166.0	-12.27	15.9	9.0	-6.90
October	216.2	314.4	+98.25	13.8	20	+6.20
November	178.4	143.0	-35.42	10.1	13	+2.90
December	48.40	7.200	-41.20	5.20	1.0	-4.20

3.2. Characterisation of samples

Soil samples were characterized for physical, chemical and biological attributes *viz*., bulk density, particle density, texture, depth of silt/clay/sand deposition, water holding capacity, soil moisture and aggregate analysis, pH, electrical conductivity, organic carbon, available macro and secondary nutrients, available boron and acid phosphatase.

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

Sl. No.	Attributes	Method	Reference
1	Bulk density	Undisturbed core sample	Blake and Hartge (1965)
2	Particle density	Pycnometer method	USDA (1953)
3	Porosity	Calculated using bulk density and particle density	USDA (1953)
4	Texture	Hydrometer method	Bouyoucos (1937)
5	Water holding capacity	Core method	Gupta and Dakshinamoorthy (1980)
6	Aggregate stability	Yoder's wet sieving method	Yoder (1936)
7	Ph	pH meter (1:2.5 soil water ratio, w/v)	Jackson (1973)
8	EC	Conductivity meter (1:2.5 soil water ratio)	Jackson (1973)
9	Organic carbon	Wet oxidation method	Walkley and Black (1934)
10	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
11	Available P	Bray No. 1 extraction and estimation using spectrophotometer	Bray and Kurtz (1945)
12	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
13	Available Ca and Mg	Versanate titration method	Hesse (1971)
14	Available S	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)
15	Available B	Hot water extraction and spectrophotometry (Azomethane-H method)	Gupta (1972)
16	Acid phosphatase activity	Colorimetric estimation of PNP released	Tabatabai and Bremer (1982)

3.3. Setting up of a Minimum Data Set (MDS) for assessment of soil quality (SQ)

A minimum data set from the analysis of physico-chemical and biological properties of soils samples were selected using Principal Component Analysis (PCA). The data were analysed to prioritize and reduce the number of indicators to be measured. Those principal components showing high eigen values best represent the variation (Shahid *et al*., 2013). Therefore, only those the PCs with eigenvalues greater than one (Kaiser, 1960) were taken into consideration. Under a particular principal component, each variable was given a factor loading which represents the contribution of that variable to the contribution of principal component. Only the highly weighted factor loading which were having absolute values within 10% of the highest factor loading were retained in the PCA (Shahid *et al*., 2013). When more than one factor was retained under a single PC, multivariate correlation coefficients were employed (Andrews *et al*., 2002). Those variables with high correlation coefficient was taken redundant and considered for MDS. If they were not correlated (correlation coefficient <0.6), then each was considered important and retained in MDS. The absolute values of factor loadings of well correlated values were selected for MDS.

3.4. Formulation of SQI, LQI and NI

3.4.1. Soil Quality Index (SQI)

The quantification of soil quality was carried out as per the procedure of Larson and Pierce, 1994. Each of the indicators was divided into four classes. Class I is the most suitable for plant growth; Class II is suitable to plant growth but with slight limitations; Class III is with more serious limitation than Class II; and Class IV is with severe limitations for plant growth. Marks of 4, 3, 2, and 1were given to class I, II, III, and IV respectively (Kundu *et al*., 2012; Mukherjee and Lal, 2014) with slight modifications. The weighted method was used to assess the soil quality index. The weight for each indicator was assigned on the basis of existing soil conditions, cropping pattern, and agro-climatic conditions (Singh *et al*., 2017). The soil quality index generated is adoptable to the AEU as well as panchayaths.

The sum of all weights is normalized to 100%. The soil quality index is computed by integrating score and appropriate weight factor of each indicator by the formula;

$$\text{SQI} = \sum_{i=1}^{n} (Wi \ * Si)$$

where, Wi and Si are the weight factor and score of the indicator respectively.
The change in soil quality was expressed in terms of relative soil quality index (RSQI) RSQI was calculated by the formula given by Karlen and Stott (1994);

$$\text{RSQI (\%)} = (\text{SQI}/\text{SQI}_{m})\ *100$$

where SQI is the calculated SQI and SQI_m is the theoretical maximum.
The maximum theoretical value of SQI considered in the study is 400. The soils with RSQI values less than 50% were rated as poor, 50-70% as medium category and greater than 70% as good quality soils (Kundu *et al.*, 2012).

3.4.2. Nutrient Index (NI)

The concept of nutrient index for the soil fertility evaluation was proposed by Parker (1951). Nutrient index ratings were calculated for all panchayaths for organic carbon, available nitrogen, available phosphorous and available potassium by the formula;

$$\text{N.I.} = (Nl * 1 + Nm * 2 + Nh * 3)/N_T$$

where, Nl = Number of samples in low category Nm= Number of samples in medium category Nh = Number of samples in high category N_T = Total number of samples.

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

Nutrient index	Value	Interpretation
I	<1.67	Low fertility status
II	1.67-2.33	Medium fertility status
III	>2.33	High fertility status

3.4.3. Land Quality Index (LQI)

LQI calculated based on soil organic carbon stock as per criteria given by Shalimadevi (2006).

Soil carbon stock was calculated by the method outlined by Batjes (1996).

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

Table 5. Land quality index ratings

SOC stock (kg m^{-2})	LQI
<3	Very low
3-6	Low
6-9	Medium
9-12	Moderate
12-15	High
>15	Very high

3.5. Generation of GIS maps

Various thematic soil maps were prepared for soil pH, soil texture, organic carbon, available macronutrients, available micronutrients, boron, soil quality index, land quality index and nutrient index using ArcGIS 10. 5.1 software through interpolation.

Inverse distance weighted (IDW) was the interpolation tool used which estimates interpolation cell values by averaging values of sample points in the vicinity of each cell. This method assumes that, with increase in distance from sampling point, the influence of value of the variable being mapped at a sampling point reduces (ESRI, 2001). The soil analysis data along with the respective geo coordinates were entered in MS excel, converted into CSV (Comma delimited) file and imported into ArcGIS mapping software. The base map with boundaries of sampled panchayaths of AEU 16 was also imported into the mapping software. IDW was selected from the spatial analyst tool. The number of sampling points were also entered and the data was interpolated. The output map thus obtained for each parameter was classified manually based on standard rating and different colours were allotted to each class.

3.6. Statistical analysis of data

Correlations between physical, chemical and biological parameters were calculated in terms of Pearson's correlation coefficient (Pearson, 1931). The significance of coefficients are expressed at the probability level of 5 % and 1 %.

RESULTS

4. RESULTS

A survey was conducted and georeferenced soils were taken from various flood affected sites of AEU 16 in Idukki district. The samples were analyzed for physical, chemical and biological attributes and the soil quality index, nutrient index and land quality index were worked out. The experimental results obtained during the course of investigation are presented in this chapter.

4.1. Survey and collection of soil samples

Survey was conducted based on a pre-designed questionnaire from the flood affected regions of AEU 16. The information regarding the basic details of farmer, crops grown, nutrient management practices followed and notable changes in the soil as well as crops at the time of flooding were collected.

The details of crops, nutrient management and size of holdings are provided in Table 6. Cardamom, pepper, nutmeg, clove, ginger, paddy, cocoa, banana, cassava, vegetables etc. were the major crops grown. Azhukal disease in cardamom, leaf and root rotting, yellowing and fungal infestation in leaves were some of the visible changes observed in crops at the time of flooding. Poor development of pod was a serious problem in areas where farmers harvested up to 6 rounds of cardamom in a year before flood. Some farmers reported that though the yield was less compared to the pre-flood scenario, further a hike in yield was observed in the second, third and fourth round of harvest after flood. The terrain of cultivation ranges from slope to plain. Mostly, cardamom is grown in slopes and paddy in levelled areas.

Submergence of areas up to seven days was observed in some areas of Rajakumari, Udumbanchola and Vandiperiyar. Sand, silt and clay deposition was found in many areas when the water receded. Hard soil pan was observed in some areas of Udumbanchola panchayath where paddy was cultivated. Many cultivation terrains were destroyed by the flow of landslide debris and deposition of sediments from flood.

Organic nutrient sources like fresh and dried cow dung, goat manure, vermicompost were preferred by most of the farmers. Dolomite was used more frequently by most of the farmers for the purpose of liming. Urea, rajphos, diammonium phosphate, muriate of potash and complex fertilizer like 18:18 and spraying of 19:19:19 as foliar spray in cardamom growing tracts were most commonly used by farmers. First round of soil drenching of urea and muriate of potash was done during May-June and the second round in November. Mulching was mostly practised with dry leaves.

Table 6. Details of field survey conducted in AEU 16 of Idukki district

Particulars	No. of farmers	Percentage
Crops		
1. Cardamom	45	59.2%
2. Pepper	35	46.1%
3. Nutmeg	20	26.3%
4. Clove	20	26.3%
5. Cassava	15	19.7%
6. Paddy	20	26.3%
7. Cocoa	5	6.58%
8. Banana	15	19.7%
9. Other crops	5	6.58%
Nutrient management		
1. INM	45	59.2%
2. Organic	15	19.7%
3. Conventional	16	21.1%
Size of holdings		
1. <2 ha	50	65.8%
2. >2ha	26	34.2%

4.2. Soil quality analysis

4.2.1. Physical parameters

Soil samples were analyzed for various physical attributes for assessing the soil quality which included bulk density, particle density, porosity, texture, water holding capacity, soil moisture and aggregate analysis.

4.2.1.1. Bulk density

The bulk density of post-flood soils of AEU ranged from 0.77 (Rajakumari) to 1.29 Mg m^{-3} (Rajakumari) (Table 7). The mean value of bulk density in the AEU was found to be 1.08 Mg m^{-3}. The lowest mean value of bulk density was observed in Nedumkandam panchayath (1.02 Mg m^{-3}) and was the highest in Rajakumari panchayath (1.14 Mg m^{-3}).

4.2.1.2. Particle density

The particle density of post-flood soils of AEU ranged from 1.60 (Senapathi) to 2.68 Mg m^{-3} (Vandiperiyar) (Table 7). The mean value of particle density in the AEU was found to be 1.99 Mg m^{-3}. The lowest mean value of particle density was observed in Rajakumari panchayath (1.92 Mg m^{-3}) and was the highest in Nedumkandam and Vandiperiyar panchayaths (2.13 Mg m^{-3}).

4.2.1.3. Porosity

The porosity of post-flood soils of AEU ranged from 20.2 (Pampadumpara) to 68.3% (Vandiperiyar) (Table 7). The mean value of porosity in the AEU was found to be 44.1%. The lowest mean value of porosity was observed in Rajakumari panchayath (40.4%) and highest in Nedumkandam panchayath (51.0%).

Table 7. Bulk density, particle density and porosity in the post-flood soils of AEU 16 in Idukki district.

Panchayath	BD (Mg m^{-3})		PD (Mg m^{-3})		Porosity (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Rajakumari	1.14±0.15	0.77-1.29	1.92±0.10	1.74-2.13	40.4±7.40	30.9-60.3
Santhanpara	1.13±0.13	0.89-1.29	1.98±0.15	1.74-2.38	42.8±7.40	30.9-56.5
Senapathi	1.03±0.11	0.88-1.19	1.94±0.23	1.60-2.30	46.0±5.60	40.6-56.0
Udumbanchola	1.03±0.07	0.95-1.15	1.97±0.24	1.67-2.48	40.8±8.60	30.9-60.3
Karunapuram	1.10±0.21	0.95-1.25	1.97±0.01	1.96-1.97	43.9±11.0	36.2-51.7
Pampadumpara	1.05±0.12	0.86-1.28	1.98±0.21	1.60-2.55	44.8±11.4	20.2-61.5
Nedumkandam	1.02±0.04	0.99-1.07	2.13±0.33	1.76-2.34	51.0±10.3	39.1-57.1
Vandiperiyar	1.06±0.15	0.85-1.25	2.13±0.33	1.65-2.68	45.9±13.2	29.4-68.3
AEU	1.08±0.13	0.77-1.29	1.99±0.21	1.60-2.68	44.1±9.20	20.2-68.3

4.2.1.4. Texture

Five textural classes were found in the post-flood soils of AEU *viz*., sandy loam, sandy clay loam, sandy clay, clay loam and clay.

The sand content of post-flood soils of AEU ranged from 43.8 to 73.8% (Table 8). The mean value of sand content in the AEU was found to be 51.4%. The lowest mean value of sand content was observed in Nedumkandam and Karunapuram panchayaths (43.8%) and was the highest in Rajakumari panchayath (62.1%).

The silt content of post-flood soils of AEU ranged from 10 to 25% (Table 8). The mean value of silt content in the AEU was found to be 15.4%. The lowest mean value of silt content was observed in Santhanpara panchayath (13.2%) and was the highest in Vandiperiyar panchayath (18.2%).

The clay content of post-flood soils of AEU ranged from 16.2 to 46.2%. The mean value of clay content in the AEU was found to be 33.2% (Table 8). The lowest mean value of clay content was observed in Rajakumari panchayath (22.9%) and was the highest in Senapathi and Nedumkandam panchayaths (41.2%).

Table 8. Sand, silt and clay content in the post-flood soils of AEU 16 in Idukki district

Panchayath	Sand (%)		Silt (%)		Clay (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Rajakumari	62.1±9.24	48.8-73.8	15.0±4.20	10.0-20.0	22.9±7.67	16.2-31.2
Santhanpara	54.5±10.2	43.8-68.8	13.2±3.17	10.0-20.0	32.3±11.0	16.2-46.2
Senapathi	46.3±4.18	43.8-53.8	12.5±2.74	10.0-15.0	41.2±4.47	36.2-46.2
Udumbanchola	46.3±4.63	43.8-53.8	16.9±5.94	10.0-15.0	36.8±4.17	31.2-46.2
Karunapuram	43.8±0.00	43.8-43.8	20.0±7.07	15.0-25.0	36.2±7.07	31.2-41.2
Pampadumpara	47.0±6.96	43.8-68.8	15.7±5.50	10.0-25.0	37.3±6.84	21.2-46.2
Nedumkandam	43.8±0.00	43.8-43.8	15.0±5.00	10.0-20.0	41.2±5.00	36.2-46.2
Vandiperiyar	45.6±3.37	43.8-53.8	18.2±5.60	10.0-25.0	36.2±4.47	31.2-46.2
AEU	51.4±9.85	43.8-73.8	15.4±4.88	10.0-25.0	33.2±9.42	16.2-46.2

4.2.1.5. Depth of silt/clay/sand deposition

The disturbances caused by floods and landslides have brought in major temporal and spatial heterogeneity in the structure and dynamics of natural communities and ecosystems. Deposition of sand, silt and clay were observed in paddy grown tracts.

Deposition of sediments with varying depth and texture was found in Rajakumari, Udumbanchola, Karunapuram and Vandiperiyar panchayaths, of which the sand deposition in Rajakumari panchayath is prominent (Table 9).

Table 9. Depth of silt/clay/sand deposition in the post-flood soils of AEU 16 in Idukki district

Panchayath	Depth of deposition	Nature of deposits
Rajakumari	30.0-50.0 cm 15.0-60.0 cm 15.0 cm	Fine sand deposits Silt deposits Clay deposits (Flood displaced large quantities of surface soil from sloped areas to levelled areas). The extend of deposition vary from moderate to severe.
Santhanpara	No visibly observable deposition	
Senapathi	No visibly observable deposition	
Udumbanchola	6.0 cm-15.0 cm	Silt deposits (moderate)
Karunapuram	20.0 cm	Silt deposits (far away from river bed)
Pampadumpara	No visibly observable deposition	
Nedumkandam	No visibly observable deposition	
Vandiperiyar	10.0 -15.0cm	Clay deposits (paddy tracts)

4.2.1.6. Soil moisture content and water holding capacity

The soil moisture content on gravimetric basis of post-flood soils of AEU ranged from 3.10 (Rajakumari) to 50.6 % (Rajakumari) (Table 10). The mean value of soil moisture content in the AEU was found to be 16.8 %. The lowest mean value of soil moisture content was observed in Karunapuram panchayath (8.53 %) and was the highest in Vandiperiyar panchayath (18.5 %).

The water holding capacity on gravimetric basis of post-flood soils of AEU ranged from 30.1 (Santhanpara) to 73.5 % (Vandiperiyar) (Table 10). The mean value of water holding capacity in the AEU was found to be 46.3 %. The lowest mean value of water holding capacity was observed in Karunapuram panchayath (39.4 %) and was the highest in Vandiperiyar panchayath (52.7 %).

Table 10. Soil moisture content and water holding capacity on gravimetric basis in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Soil moisture content (%)		Water holding capacity (%)	
	Mean±SD	Range	Mean±SD	Range
Rajakumari	15.20±11.7	3.10-50.6	44.2±4.50	39.5-54.2
Santhanpara	15.6±9.70	5.48-39.1	41.8±7.96	30.1-56.7
Senapathi	14.9±7.60	6.07-28.3	48.2±6.35	39.7-55.6
Udumbanchola	17.9±13.38	4.55-35.9	43.7±5.06	36.8-48.5
Karunapuram	8.53±5.01	4.98-12.1	39.4±12.3	30.7-48.0
Pampadumpara	20.3±8.62	9.11-35.7	49.3±9.99	39.0-73.0
Nedumkandam	15.9±11.1	5.38-27.6	49.2±3.16	45.6-51.4
Vandiperiyar	18.5±9.12	4.30-31.7	52.73±10.59	42.4-73.5
AEU	16.8±10.1	3.10-50.6	46.26±8.39	30.1-73.5

4.2.1.6. Aggregate stability

The water stable aggregates of post-flood soils of AEU ranged from 33.8 (Vandiperiyar) to 92.4 % (Rajakumari) (Table 11). The mean value of water stable aggregates in the AEU was found to be 67.5 %. The lowest mean value of water stable aggregates was observed in Nedumkandam panchayath (63.2 %) and was the highest in Karunapuram panchayath (78.9 %).

The mean weight diameter of post-flood soils of AEU ranged from 0.30 (Vandiperiyar) to 2.62 mm (Pampadumpara) (Table 11). The mean value of mean weight diameter in the AEU was found to be 0.96 mm. The lowest mean value of mean weight diameter was observed in Vandiperiyar panchayath (0.72 mm) and was the highest in Karunapuram panchayath (1.81 mm).

Table 11. Water stable aggregates and mean weight diameter in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Water stable aggregates (%)		Mean weight diameter (mm)	
	Mean±SD	Range	Mean±SD	Range
Rajakumari	72.0±7.49	59.8-92.4	1.08±0.45	0.51-2.22
Santhanpara	63.4±6.79	54.0-71.3	0.88±0.37	0.6-2.05
Senapathi	66.6±6.05	54.4-70.5	0.87±0.10	0.76-0.99
Udumbanchola	67.0±9.78	53.2-75.6	0.87±0.19	0.63-1.04
Karunapuram	78.9±5.74	74.9-83.0	1.81±0.22	1.65-1.96
Pampadumpara	68.6±9.59	53.4-86.4	0.98±0.51	0.56-2.62
Nedumkandam	63.2±11.3	53.4-75.6	1.34±0.87	0.77-2.34
Vandiperiyar	63.7±10.3	33.8-69.8	0.72±0.20	0.30-0.92
AEU	67.5±8.98	33.8-92.4	0.96±0.43	0.30-2.62

4.2.2. Chemical parameters

Soil samples were analysed for various chemical attributes for assessing the soil quality which included pH, electrical conductivity, organic carbon, available nitrogen, available phosphorous, available potassium, available calcium, available magnesium, available sulphur and available boron.

4.2.2.1. Soil pH, EC and organic carbon

The pH of post-flood soils of AEU ranged from 4.62 (Rajakumari) to 6.92 (Santhanpara) (Table 12). The mean value of pH in the AEU was found to be 5.78. The lowest mean value of pH was observed in Vandiperiyar panchayath (5.21) and was the highest in Nedumkandam and Pampadumpara panchayath (6.16).

The EC of post-flood soils of AEU ranged from 0.04 (Santhanpara and Pampadumpara) to 0.52 dS m^{-1}(Santhanpara) (Table 12). The mean value of EC in the AEU was found to be 0.16 dS m^{-1}. The lowest mean value of EC was observed in Senapathi and Pampadumpara panchayaths (0.12 dS m^{-1}) and was the highest in Santhanpara panchayath (0.18 dS m^{-1}).

The organic carbon of post-flood soils of AEU ranged from 0.63 (Santhanpara) to 4.68% (Rajakumari) (Table 12). The mean value of organic carbon in the AEU was found to be 2.35%. The lowest mean value of organic carbon was observed in Nedumkandam panchayath (1.43%) and was the highest in Karunapuram panchayath (3.22%).

Table 12. Soil pH, EC and organic carbon status in the post-flood soils of AEU 16 in Idukki district.

Panchayath	pH		EC (dS m^{-1})		OC (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Rajakumari	5.79±0.63	4.62-6.87	0.19±0.09	0.09-0.43	2.85±0.98	1.62-4.68
Santhanpara	5.94±0.67	4.76-6.92	0.18±0.13	0.04-0.52	2.34±0.75	0.63-3.90
Senapathi	5.81±0.56	5.05-6.5	0.12±0.05	0.06-0.20	2.04±0.54	1.34-2.99
Udumbanchola	5.77±0.55	4.72-6.47	0.13±0.07	0.05-0.24	2.20±0.45	1.20-2.70
Karunapuram	5.89±0.63	5.44-6.33	0.24±0.07	0.19-0.29	3.22±1.56	2.12-4.32
Pampadumpara	6.16±0.61	4.8-6.64	0.12±0.07	0.04-0.28	2.35±0.77	0.71-3.10
Nedumkandam	6.16±0.53	5.64-6.69	0.17±0.10	0.06-0.24	1.43±0.44	1.04-1.90
Vandiperiyar	5.21±0.44	4.73-6.06	0.17±0.13	0.05-0.42	1.88±0.60	0.93-2.75
AEU	5.78±0.62	4.62-6.92	0.16±0.10	0.04-0.52	2.35±0.84	0.63-4.68

4.2.2.2. Available primary nutrients

Status of available N, P and K of different panchayaths in AEU 16 are presented in the Table 13. The available N of post-flood soils of AEU ranged from 151 (Senapathi) to 389 kg ha^{-1} (Pampadumpara). The mean value of available N in the AEU was found to be 247 kg ha^{-1}. The lowest mean value of available N was observed in Vandiperiyar panchayath (208 kg ha^{-1}) and was the highest in and Karunapuram panchayath (282 kg ha^{-1}).

The available P of post-flood soils of AEU ranged from 2.90 (Nedumkandam) to 191 kg ha^{-1}(Pampadumpara). The mean value of available P in the AEU was found to be 42.0 kg ha^{-1}. The lowest mean value of available P was observed in Nedumkandam panchayath (6.76 kg ha^{-1}) and was the highest in Karunapuram panchayath (58.2 kg ha^{-1})

The available K of post-flood soils of AEU ranged from 22.4 (Santhanpara) to 1725 kg ha^{-1}(Karunapuram). The mean value of available K in the AEU was found to be 574 kg ha^{-1}. The lowest mean value of available K was observed in Senapathi panchayath (312 kg ha^{-1}) and highest in and Karunapuram panchayath (1086 kg ha^{-1}).

Table 13. Available N, P and K status in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Rajakumari	268±48.8	188-364	56.1±46.5	3.70-165	606±401	168-1613
Santhanpara	248±57.4	163-339	40.5±37.2	9.18-154	505±392	22.4-1520
Senapathi	238±81.3	151-376	18.2±12.0	5.94-35.8	312±219	33.6-549
Udumbanchola	246±32.1	213-314	51.0±58.2	5.04-151	648±342	291-1254
Karunapuram	282±8.87	276-289	58.2±11.1	50.4-66.1	1086±903	448-1725
Pampadumpara	248±49.3	163-389	47.1±50.4	5.94-191	674±433	146-1366
Nedumkandam	263±62.7	201-326	6.76±7.44	2.90-15.1	508±301	291-851
Vandiperiyar	208±21.3	176-251	27.4±23.9	3.81-67.8	499±238	168-952
AEU	247±51.2	151-389	42.0±42.1	0.56-191	574±384	22.4-1725

4.2.2.3. Available secondary nutrients

Status of available Ca, Mg and available S of different panchayaths in AEU 16 are presented in the Table 14. The available Ca of post-flood soils of AEU ranged from 120 (Vandiperiyar) to 1480 mg kg^{-1}(Santhanpara). The mean value of available Ca in the AEU was found to be 847 mg kg^{-1}. The lowest mean value of available Ca was observed in Vandiperiyar panchayath (540 mg kg^{-1}) and was the highest in Nedumkandam panchayath (1060 mg kg^{-1}).

The available Mg of post-flood soils of AEU ranged from 48.0 (Udumbanchola) to 780 mg kg^{-1}(Rajakumari). The mean value of available Mg in the AEU was found to be 222 mg kg^{-1}. The lowest mean value of available Mg was observed in Karunapuram panchayath (156 mg kg^{-1}) and was the highest in Nedumkandam panchayath (280 mg kg^{-1}).

The available S of post-flood soils of AEU ranged from 0.50 (Pampadumpara) to 75.0 mg kg^{-1}(Rajakumari). The mean value of available S in the AEU was found to be 15.0 mg kg^{-1}. The lowest mean value of available S was observed in Udumbanchola panchayath (5.00 mg kg^{-1}) and was the highest in and Rajakumari panchayath (21.6 mg kg^{-1}).

Table 14. Available Ca, Mg and available S status in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Available Ca (mg kg^{-1})		Available Mg (mg kg^{-1})		Available S (mg kg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Rajakumari	893±370	340-1480	249±147	120-780	21.6±24.0	1.00-75.0
Santhanpara	945±382	220-1480	252±96.8	96.0-528	13.9±16.4	1.00-61.5
Senapathi	800±451	180-1340	210±78.4	108-288	18.4±27.8	1.50-74.5
Udumbanchola	898±390	160-1480	197±75.9	48.0-288	5.00±3.30	1.00-10.0
Karunapuram	860±509	500-1220	156±67.9	108-204	10.3±8.80	4.00-16.5
Pampadumpara	873±292	360-1460	219±61.6	108-336	13.8±13.3	0.50-46.0
Nedumkandam	1060±362	680-1400	280±120.2	156-396	7.2±9.40	1.00-18.0
Vandiperiyar	540±235	120-920	164±32.8	96.0-216	15.8±16.0	2.00-52.0
AEU	847±363	120-1480	222±99.5	48.0-780	15.0±18.0	0.50-75.0

4.2.2.4. Available boron

The available B of post-flood soils of AEU ranged from 0.01 (Rajakumari and Pampadumpara) to 0.74 mg kg^{-1}(Rajakumari) (Table 15). The mean value of available B in the AEU was found to be 0.12 mg kg^{-1}. The lowest mean value of available B was observed in Karunapuram panchayath (0.03 mg kg^{-1}) and was the highest in Rajakumari panchayath (0.18 mg kg^{-1}).

Table 15. Available boron in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Available B (mg kg^{-1})	
	Mean±SD	Range
Rajakumari	0.18±0.20	0.01-0.74
Santhanpara	0.11±0.09	0.02-0.31
Senapathy	0.04±0.03	0.02-0.1
Udumbanchola	0.16±0.16	0.02-0.44
Karunapuram	0.03±0.01	0.02-0.04
Pampadumpara	0.11±0.17	0.01-0.66
Nedumkandam	0.04±0.03	0.02-0.08
Vandiperiyar	0.09 ± 0.06	0.03-0.23
AEU	0.12±0.14	0.01-0.74

4.2.3. Biological parameters

4.2.3.1. Acid phosphatase activity

The activity of acid phosphatase of post-flood soils of AEU ranged from 5.36 (Udumbanchola) to 85.2 µg PNP produced g $soil^{-1}$ h^{-1} (Senapathi) (Table 16). The mean value of acid phosphatase activity in the AEU was found to be 29.0 µg PNP produced g $soil^{-1}$ h^{-1}. The lowest mean value of acid phosphatase activity was observed in Vandiperiyar panchayath (18.9 µg PNP produced g $soil^{-1}$ h^{-1}) and highest in Senapathi panchayath (54.7 µg PNP produced g $soil^{-1}$ h^{-1}).

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

Panchayath	Acid phosphatase activity (µg PNP* produced g soil^{-1} h^{-1})	
	Mean±SD	Range
Rajakumari	31.8±14.7	9.82-61.5
Santhanpara	26.5±16.9	6.91-67.4
Senapathi	54.7±23.5	26.3-85.2
Udumbanchola	25.2±15.6	5.36-58.4
Karunapuram	31.4±18.8	18.1-44.7
Pambadupara	28.1±15.8	11.8-65.5
Nedumkandam	22.1±9.87	10.7-27.8
Vandiperiyar	18.9±4.64	12.2-28.1
AEU	29.0±16.9	5.36-85.2

*PNP – Para nitrophenol

4.3. Formulation of minimum data set and assessment of soil quality index

4.3.1. Formulation of minimum data set

Twenty-one attributes were analysed using principal component analysis (PCA) to develop a minimum data set (MDS). The parameters used for PCA were bulk density, particle density, porosity, per cent sand, per cent silt, per cent clay, soil moisture content, water holding capacity, mean weight diameter, water stable aggregates, pH, EC, organic carbon available primary and secondary nutrients, available B and acid phosphatase activity.

The PCA extracted eight principal components with eigen value greater than one and were selected as the MDS (Table 17). The eight principle components explained 17.3%, 14.6%, 9.80%, 7.90%, 7.20%, 6.20%, 5.50% and 4.90% variance respectively

The factor loading of variables in each PC group denotes the contribution of that variable to the PC group. Only highly weighted variables having absolute values of factor loading within 10% of the highest factor loading in the PC group were retained from each PC for MDS (Shahid *et al*., 2013). Multivariate correlation coefficients were employed to set the MDS when more than one factor was retained under a single PC group (Andrews *et al.,* 2002). Those highly weighted factors which were not correlated (*r* <0.6) was retained in MDS. Among well correlated variables, the one with highest absolute value of factor loading was chosen for MDS.

In the first PC, soil organic carbon had the highest factor loading, so was selected for MDS (Table 18). In the second PC group since percent sand had higher correlation values and the others viz., per cent clay and bulk density had lower correlation values, per cent sand was eliminated and percent clay as well as bulk density are retained. In third, fourth and fifth PC groups, pH, available boron and per cent silt were retained respectively. In sixth PC group, since EC and available potassium had *r* <0.6, so were retained. The available nitrogen as well as soil moisture content were retained in the seventh and eight PC groups respectively.

Table 17. Results of principal component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalues	**3.64**	**3.01**	**2.06**	**1.65**	**1.51**	**1.29**	**1.16**	**1.03**
Proportion	0.173	0.146	0.980	0.790	0.720	0.620	0.550	0.490
Cumulative proportion	0.173	0.319	0.418	0.496	0.568	0.629	0.685	0.734

Eigen vectors

Parameters	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
pH	0.284	0.084	**-0.388**	-0.044	0.315	-0.090	-0.178	-0.033
EC (dS m^{-1})	0.195	0.065	-0.218	-0.142	0.119	**0.454**	0.114	0.049
Organic carbon (%)	**0.396**	0.013	0.159	0.133	-0.077	0.046	0.174	0.043
Available N (kg ha^{-1})	0.227	0.023	0.039	-0.008	0.076	-0.082	**0.712**	-0.025
Available P (kg ha^{-1})	0.244	-0.105	0.245	-0.262	-0.334	-0.006	0.025	-0.045
Available K (kg ha^{-1})	0.247	0.057	0.067	0.126	0.273	**0.468**	-0.26	0.016
Available Ca (mg kg^{-1})	0.333	0.157	-0.337	-0.033	0.168	-0.093	0.004	0.07
Available Mg (mg kg^{-1})	0.233	-0.078	-0.247	0.035	0.126	-0.207	-0.155	-0.132
Available S (mg kg^{-1})	0.230	0.137	0.025	0.326	-0.239	0.130	0.072	0.100
Available B (mg kg^{-1})	0.089	0.043	0.199	**0.513**	-0.060	0.320	-0.114	-0.115
Acid phosphatase activity (µg PNP g^{-1} h^{-1})	0.267	0.158	-0.220	-0.096	-0.275	-0.171	0.112	0.059
Bulk density (Mg m^{-3})	-0.003	**-0.479**	-0.066	0.051	0.192	-0.109	-0.084	-0.024
moisture%	0.023	0.05	0.143	0.284	0.12	-0.198	-0.104	**0.729**
Water holding capacity (%)	-0.021	0.256	0.241	-0.092	0.301	-0.194	0.119	0.346
Particle density (Mg m^{-3})	-0.298	0.054	-0.229	-0.260	0.057	0.275	0.002	0.317
Mean weight diameter (mm)	0.245	-0.121	0.212	-0.408	-0.080	0.118	-0.247	0.125
Water stable aggregates (%)	0.285	-0.103	0.295	-0.32	-0.054	-0.037	-0.231	0.122
Sand%	0.019	**-0.450**	-0.235	0.072	-0.196	0.132	0.119	0.276
Silt%	-0.031	0.002	0.315	-0.162	**0.500**	0.162	0.254	-0.174
Clay%	-0.004	**0.470**	0.082	0.009	-0.055	-0.223	-0.256	-0.198
Porosity (%)	-0.152	0.385	-0.141	-0.190	-0.250	0.292	0.065	0.120

Table 18. Minimum data set (MDS) obtained from PCA

PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Organic carbon	Clay %	pH	Available B	Silt %	EC	Available N	Soil moisture
	Bulk density				Available K		

4.3.2. Assessment of soil quality index

Soil quality index was worked out using the MDS. The parameters in the MDS were assigned appropriate weight and scores. The weight for each indicator was given (weight factors) according to existing soil conditions, cropping pattern and agro-climatic conditions for assessing soil quality indices (Singh *et al*., 2017).

The scoring for each indicator was done according to the scoring classes put forward by Kundu *et al*. (2012) and Mukherjee and Lal (2014) with slight modifications (Table 19).

Table 19. Soil quality indicators, their weights and classes with scores

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Organic carbon (%)	20.0	>1.00	0.75-1.00	0.50-0.75	<0.50
Texture Clay % Silt %	10.0 5.00 5.00	Loam	Clay loam/ Sandy loam/ Sandy clay loam	Sandy clay/ loamy sand	Grit
Bulk density (Mg m^{-3})	15.0	1.30-1.40	1.20-1.30/1.40-1.50	1.10-1.20/1.50-1.60	<1.10/>1.60
pH	10.0	6.50-7.50	6.00-6.50	6.00-5.50	<5.50
Available boron (mg kg^{-1})	10.0	>1.50	0.70-1.50	0.50-0.70	<0.50
EC (dS m^{-1})	5.00	<2.00	2.00-4.00	4.00-8.00	>8.00
Available potassium (kg ha^{-1})	10.0	>280	200-280	120-200	<120
Available nitrogen (kg ha^{-1})	10.0	>560	420-560	280-420	<280
Soil moisture content (%)	10.0	>15.0	12.0-15.0	9.0-12.0	<9.0

The mean, standard deviation and range of SQI and RSQI are presented in Table 20. The SQI of AEU ranged from 165 (Vandiperiyar) to 295 (Rajakumari). The mean of SQI in post-flood soils of AEU is 236. The lowest mean of SQI was found in Santhanpara panchayath (221) and highest in Pampadumpara panchayath (244). The RSQI of AEU ranged from 41.3 (Vandiperiyar) to 73.8 % (Pampadumpara). The mean value of RSQI of AEU is 59.1%. The lowest mean of RSQI was found in Senapathi panchayath (55.2 %) and highest in Pampadumpara panchayath (60.9 %).

Table 20. SQI and RSQI in the post-flood soils of AEU 16 in Idukki district

Panchayath	SQI		RSQI (%)	
	Mean±SD	Range	Mean±SD	Range
Rajakumari	243±29.2	185-295	60.8±7.30	46.3-73.8
Santhanpara	238±32.6	190-290	59.6±8.14	47.5-72.5
Senapathi	221±14.6	195-235	55.2±3.66	48.8-58.8
Udumbanchola	229±19.9	195-250	57.3±4.97	48.8-62.5
Karunapuram	233±3.50	230-235	58.1±0.88	57.5-58.8
Pampadumpara	244±29.1	185-295	60.9±7.26	46.3-73.8
Nedumkandam	238±25.2	215-265	59.6±6.29	53.8-66.3
Vandiperiyar	227±29.5	165-260	56.7±7.38	41.3-65.0
AEU	236±27.7	165-295	59.1±6.93	41.3-73.8

4.4. Nutrient Index

Panchayath wise nutrient index worked for organic carbon and available primary nutrients are presented in the Table 21. Nutrient index for organic carbon was high for all the panchayaths except for Nedumkandam panchayath which has medium nutrient index (2.73). The highest value was observed in Rajakumari and Karunapuram panchayaths (3.00). Nutrient index for available nitrogen was low in all panchayaths and the least was observed in Vandiperiyar panchayath (1.00). Nutrient index for available phosphorous was high in Karunapuram (3.00), Rajakumari, Santhanpara and Vandiperiyar panchayaths, was medium in Udumbanchola and Pampadumpara panchayaths and was low in Nedumkandam panchayath (1.33). Nutrient index for available potassium was high in all panchayaths except in Senapathi panchayath which has medium (2.33).

Table 21. Nutrient indices of organic carbon, available N, P and K at panchayath level

Panchayath	Nutrient Index							
	Organic carbon	Status	Available N	Status	Available P	Status	Available K	Status
Rajakumari	3.00	High	1.33	Low	2.55	High	2.77	High
Santhanpara	2.79	High	1.36	Low	2.43	High	2.50	High
Senapathi	2.83	High	1.33	Low	2.00	Medium	2.33	Medium
Udumbanchola	2.88	High	1.13	Low	2.25	Medium	3.00	High
Karunapuram	3.00	High	1.50	Low	3.00	High	3.00	High
Pambadupara	2.86	High	1.14	Low	2.29	Medium	2.93	High
Nedumkandam	2.33	Medium	1.33	Low	1.33	Low	3.00	High
Vandiperiyar	2.73	High	1.00	Low	2.36	High	2.90	High

4.5. Land quality index

The land quality index of post-flood soils of AEU ranged from 0.93 (Pampadumpara) to 8.78 kg m^{-2} (Rajakumari) (Table 22). The mean value of AEU was found to be 3.85 kg m^{-2}. The lowest mean value was found in Nedumkandam panchayath (2.21 kg m^{-2}) and highest in Karunapuram panchayath (5.07 kg m^{-2}).

Table 22. Soil organic carbon stock and LQI in the post-flood soils of AEU 16 in Idukki district.

Panchayath	Soil carbon stock (Mg ha^{-1})	LQI (kg m^{-2})	
	Range	Mean±SD	Range
Rajakumari	23.8-87.8	4.83±1.65	2.38-8.78
Santhanpara	11.2-64.9	3.91±1.24	1.12-6.49
Senapathi	23.9-39.5	3.13±0.47	2.65-3.95
Udumbanchola	20.0-39.0	3.39±0.62	2.00-3.90
Karunapuram	39.8-61.6	5.07±1.54	3.98-6.16
Pambadupara	9.30-52.7	3.86±1.50	0.93-6.37
Nedumkandam	15.8-30.5	2.21±0.76	1.58-3.05
Vandiperiyar	11.9-39.8	3.15±1.07	1.19-4.86
AEU	9.30-87.8	3.85±1.43	0.93-8.78

4.6. Generation of maps using GIS technique

Thematic maps were prepared using ArcGIS 10.5.1 software. Spatial distribution in soil pH, organic carbon, available primary and secondary nutrients, available boron, soil quality index, land quality index as well as panchayath wise nutrient indices for organic carbon and primary nutrients were mapped.

4.7. Statistical Analysis of the data

Correlation between the analyzed parameters were worked out using Pearson's correlation coefficient. The results are summarized in Table 23, 24 and 25.

4.7.1. Correlation between physical parameters

Correlation between physical parameters is presented in Table 23. Water holding capacity (WHC) showed a significant negative correlation with bulk density (BD) (-0.35^{**}). Water stable aggregates (WSA) showed a negative significant correlation with particle density (PD) (-0.27^{*}) and strongly as well as positive correlation with mean weight diameter (MWD) (0.64^{**}). Sand content in soils showed a significant positive correlation with bulk density (0.51^{**}) and negative correlation with water holding capacity (-0.39^{**}). Silt content of soils showed a significant positive correlation with water holding capacity (0.25^{*}) and negative correlation with sand content (-0.33^{**}). Clay content of soils showed a significant negative correlation with bulk density (-0.54^{**}), positive correlation water holding capacity (0.28^{*}) and a highly significant negative correlation with sand content (-0.87^{**}). Porosity showed a highly significant negative correlation with bulk density (-0.78^{**}), a significant positive correlation with water stable particle density (0.52^{**}) and sand content (-0.23^{*}) and a significant positive correlation with clay content (0.36^{**}).

Table 23. Correlation between physical parameters

Parameters	BD	SMC	WHC	PD	MWD	WSA	Sand	Silt	Clay	Porosity
BD	1.00									
SMC	-0.01	1.00								
WHC	-0.35**	0.20	1.00							
PD	0.04	-0.03	0.01	1.00						
MWD	0.07	-0.06	-0.04	-0.14	1.00					
WSA	0.09	0.00	0.11	-0.27*	0.64**	1.00				
Sand	0.51**	-0.05	-0.39**	0.03	0.08	0.01	1.00			
Silt	0.01	-0.03	0.25*	0.02	0.11	0.07	-0.33**	1.00		
Clay	-0.54**	0.07	0.28*	-0.04	-0.14	-0.05	-0.87**	-0.17	1.00	
Porosity	-0.78**	-0.09	0.07	0.52**	-0.11	-0.23*	-0.30	-0.09	0.36**	1.00

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

4.7.2. Correlation between physical, chemical and biological parameters

Correlation physical, chemical and biological parameters is given in Table 24. Soil pH showed a significant positive correlation with bulk density (0.33**), WHC (0.28*), sand (0.47**) and clay content (0.32**). EC showed a significant negative correlation with clay content (-0.24*). Available P showed a significant negative correlation with WHC (-0.46**), MWD (-0.31**) and clay content of soils (-0.30**). Available K showed a significant positive correlation with WHC (0.23*) and MWD

(0.44**). Available Ca showed a significant positive correlation with WHC (0.41**) and MWD (0.45**).

Table 24. Correlation physical, chemical and biological parameters

Parameters	BD	SMC	WHC	PD	MWD	WSA	Sand	Silt	Clay
pH	0.33**	0.22	0.28*	0.21	0.22	0.05	0.47**	0.09	0.32**
EC	-0.01	-0.04	-0.08	-0.04	0.02	-0.03	-0.16	0.14	-0.24*
OC	-0.01	-0.13	0.12	-0.00	-0.03	0.07	0.04	-0.04	0.10
N	-0.06	-0.00	0.00	0.07	-0.14	0.02	0.31	-0.12	0.05
P	-0.13	0.07	-0.46**	-0.22	-0.31**	-0.19	-0.16	-0.17	-0.30**
K	0.10	0.07	0.23*	0.07	0.44**	0.21	0.11	0.12	0.09
Ca	0.10	0.08	0.41**	0.11	0.45**	0.17	0.08	0.14	0.04
Mg	-0.03	0.03	0.02	-0.02	0.07	-0.10	-0.06	0.12	-0.03
S	-0.06	-0.02	-0.03	0.16	0.02	0.12	-0.11	-0.10	-0.14
B	0.06	-0.02	-0.00	-0.07	-0.08	0.04	0.12	-0.07	0.11
Phosphatase	-0.04	0.08	-0.17	-0.09	-0.13	-0.12	0.05	-0.18	0.03

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

4.7.2. Correlation between chemical and biological parameters

Correlation between chemical and biological parameters is given in Table 25. Soil pH showed a significant positive correlation with EC. Available N showed a significant positive correlation with organic carbon (0.45**). Available P showed a significant positive correlation with organic carbon (0.39**). Available K showed a significant positive correlation with pH (0.28*), EC (0.36**) and organic carbon (0.38**). Available Ca showed a highly significant positive correlation with pH (0.75**), a significant positive correlation with EC (0.29*), organic carbon (0.34**), available N (0.27*) and available K (0.25*). Available Mg showed a significant positive correlation with pH (0.45**), organic carbon (0.25*) and available Ca (0.35**). Available S showed a significant positive correlation with organic carbon (0.29**). Available B showed a significant positive correlation with organic carbon (0.28*), available K (0.26*) and available S (0.34**). Acid phosphatase activity showed a significant positive correlation with pH (0.33**), organic carbon (0.28*), available Ca (0.47**) and available S (0.32**).

Table 25. Correlation between chemical and biological parameters

Parameters	pH	EC	OC	N	P	K	Ca	Mg	S	B	Phosphatase
Ph	1.00										
EC	0.28*	1.00									
OC	0.17	0.17	1.00								
N	0.13	0.16	0.45**	1.00							
P	-0.09	0.10	0.39**	0.14	1.00						
K	0.28*	0.36**	0.38**	0.01	0.04	1.0					
Ca	0.75**	0.29*	0.34**	0.27*	0.06	0.25*	1.00				
Mg	0.45**	0.13	0.25*	0.09	0.05	0.03	0.35**	1.00			
S	0.08	0.16	0.29**	0.16	0.07	0.19	0.17	0.17	1.00		
B	-0.07	-0.06	0.28*	-0.01	-0.01	0.26*	-0.01	-0.03	0.34**	1.00	
Phosphatase	0.33**	0.22	0.28*	0.21	0.22	0.05	0.47**	0.09	0.32**	-0.12	1.00

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

DISCUSSION

5. DISCUSSION

The present study was undertaken for the assessment of soil quality in the post-flood soils of AEU 16 and generation of GIS maps. For this purpose, seventy-six georeferenced soil samples were analysed for its physical chemical and biological attributes. Principal component analysis of twenty-one parameters was carried out to set a minimum data set (MDS). The PCA resulted in an MDS consisting of ten parameters which was used for the assessment of soil quality index (SQI) and relative soil quality index (RSQI). The results of the experiments are discussed in this chapter with supporting studies from the literature.

5.1. Physical attributes

5.1.1. Bulk density

The bulk density of post-flood soils of AEU ranged from 0.77 (Rajakumari) to 1.29 Mg m^{-3} (Rajakumari). About 80.3 per cent of soil samples were found to have a low bulk density (less than 1.2 Mg m^{-3}) and 19.7 per cent of soil samples had a bulk density ranged from 1.2 to 1.4 Mg m^{-3} (Fig 3). Since the bulk density of soil increases with increase in sand content, it was found to be higher in Rajakumari panchayath as the sand content was found to be more in the soils. The general low status of bulk density in the AEU may be due to the higher organic carbon content (Sakin, 2012). Low bulk density has resulted in poor water retension.

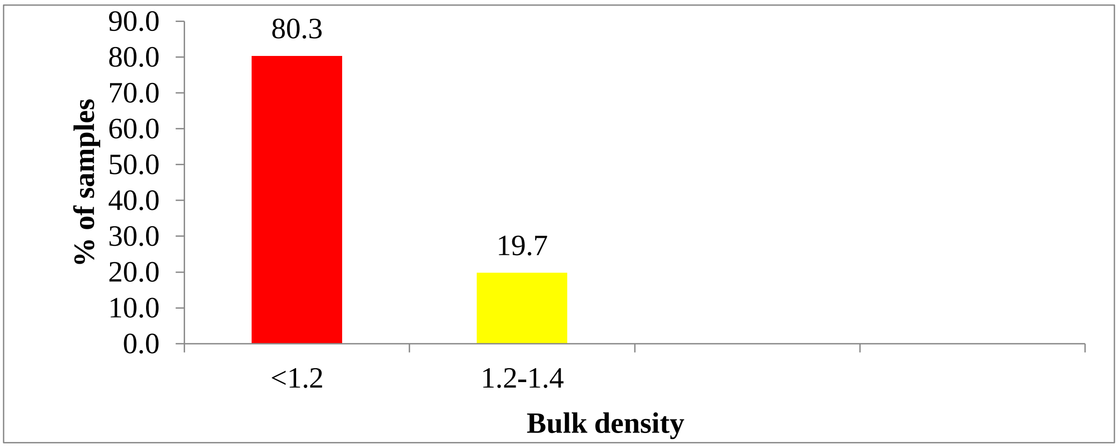

Fig 3. Frequency distribution of bulk density (Mg m^{-3}) in the post-flood soils of AEU 16 in Idukki district

5.1.2. Particle density

The particle density of post-flood soils of AEU ranged from 1.60 (Senapathi) to 2.68 Mg m^{-3} (Vandiperiyar). About 88.2 per cent of soil sample had a particle density less than 2.2 Mg m^{-3}, 5.26 per cent in the range of 2.2 to 2.4 Mg m^{-3}, 3.95 per cent in the range of 2.4 and 2.6 Mg m^{-3} and 2.63 per cent had greater than 2.6 Mg m^{-3} (Fig 4). Particle density increases with increase in fineness of soil. The particle density was found to be more in Vandiperiyar panchayath due to clayey texture of soil and was found to be low in Rajakumari panchayath due to sandy loam and sandy clay loam texture of soils. In general, value of particle density and bulk density obtained for the samples may be ascribed to the higher organic matter content and higher clay content of the soil.

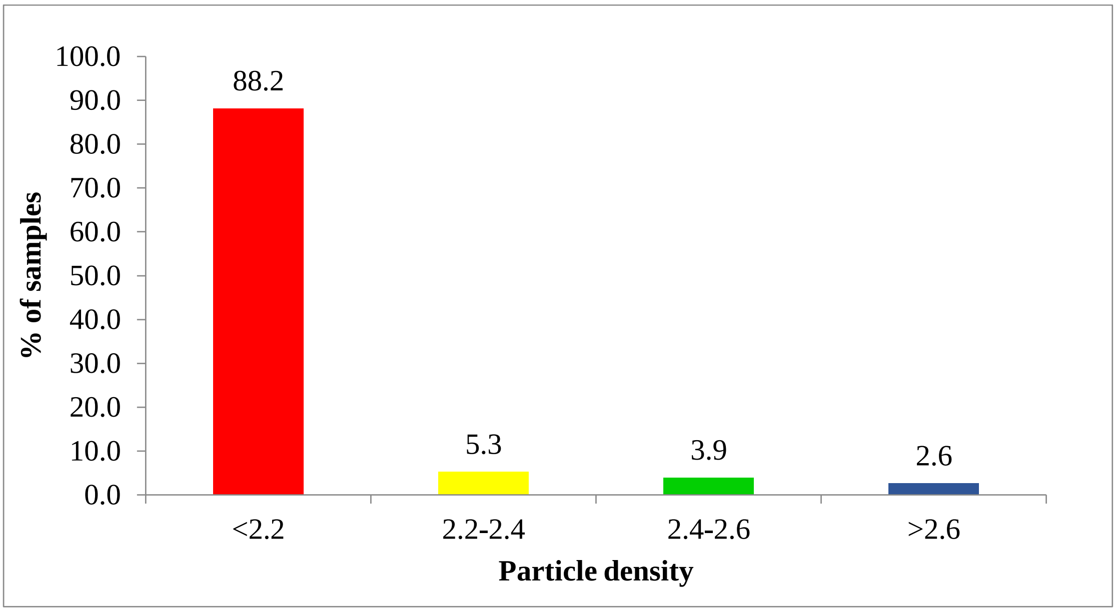

Fig 4. Frequency distribution of particle density (Mg m^{-3}) in the post-flood soils of AEU 16 in Idukki district

5.1.3. Porosity

The porosity of post-flood soils of AEU ranged from 20.2 (Pampadumpara) to 68.3% (Vandiperiyar). Less than 3.95 per cent of soil samples had a porosity less than 30 per cent, 68.4 per cent ranged from 30 to 50 % and 27.6 per cent ranged from 50 to

70% (Fig 5). The porosity of soil samples was found to increase with the fineness of soil i.e., higher for clayey texture. Porosity showed a lower value for soil samples having higher bulk density and were significantly and negatively correlated (-0.78).

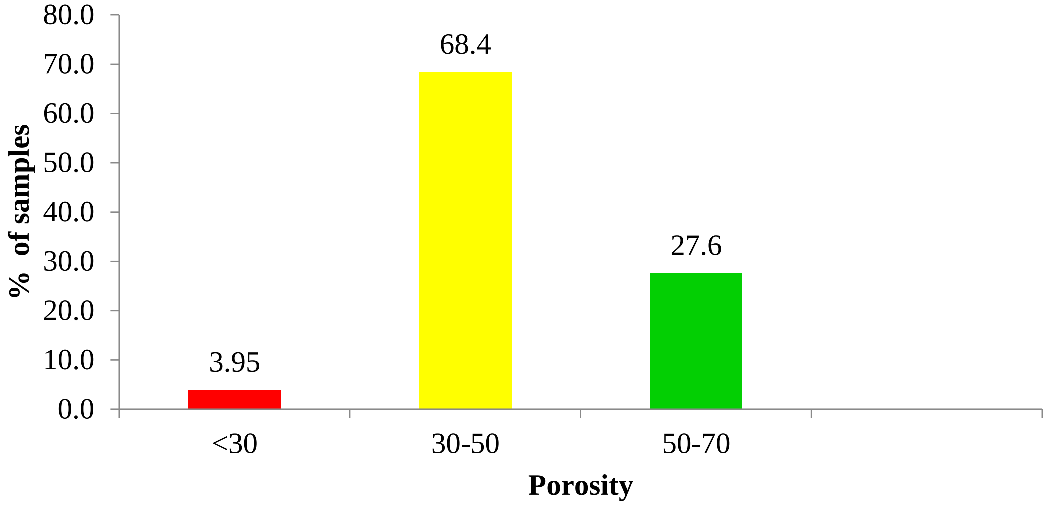

Fig 5. Frequency distribution of porosity (%) in the post-flood soils of AEU 16 in Idukki district

5.1.4. Texture

Sandy loam soils were found in some parts of Rajakumari, Santhanpara and Senapathi panchayaths. Sandy clay loam soils were found in some parts of Rajakumari, Pampadumpara and Nedumkandam panchayaths. Sandy clay soils were found in Santhanpara, Senapathy and Udumbanchola, Pampadumpara and Vandiperiyar panchayaths. Clay loam soils were found in parts of Udumbanchola, Nedumkandam, Pampadumpara, Karunapuram and Vandiperiyar.

Moderately coarse textured sandy soils form 17.1 % (Fig 6) of the total samples. Moderately fine textured loamy textured soils (*viz*., clay loam (23.7%) and sandy clay loam (17.1%)) together forms 40.8% of the total samples analysed in the AEU 16. Fine textured clayey soils (*viz*., sandy clay (15.8 %) and clay (26.3 %)) constitute 42.1 % rendering the proper management of physical properties for optimising crop productivity. Deposition of sediments with varying depth and texture was found in

Rajakumari, Udumbanchola, Karunapuram and Vandiperiyar panchayaths, of which the sand deposition in Rajakumari panchayath is prominent. Spatial distribution of texture in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 7.

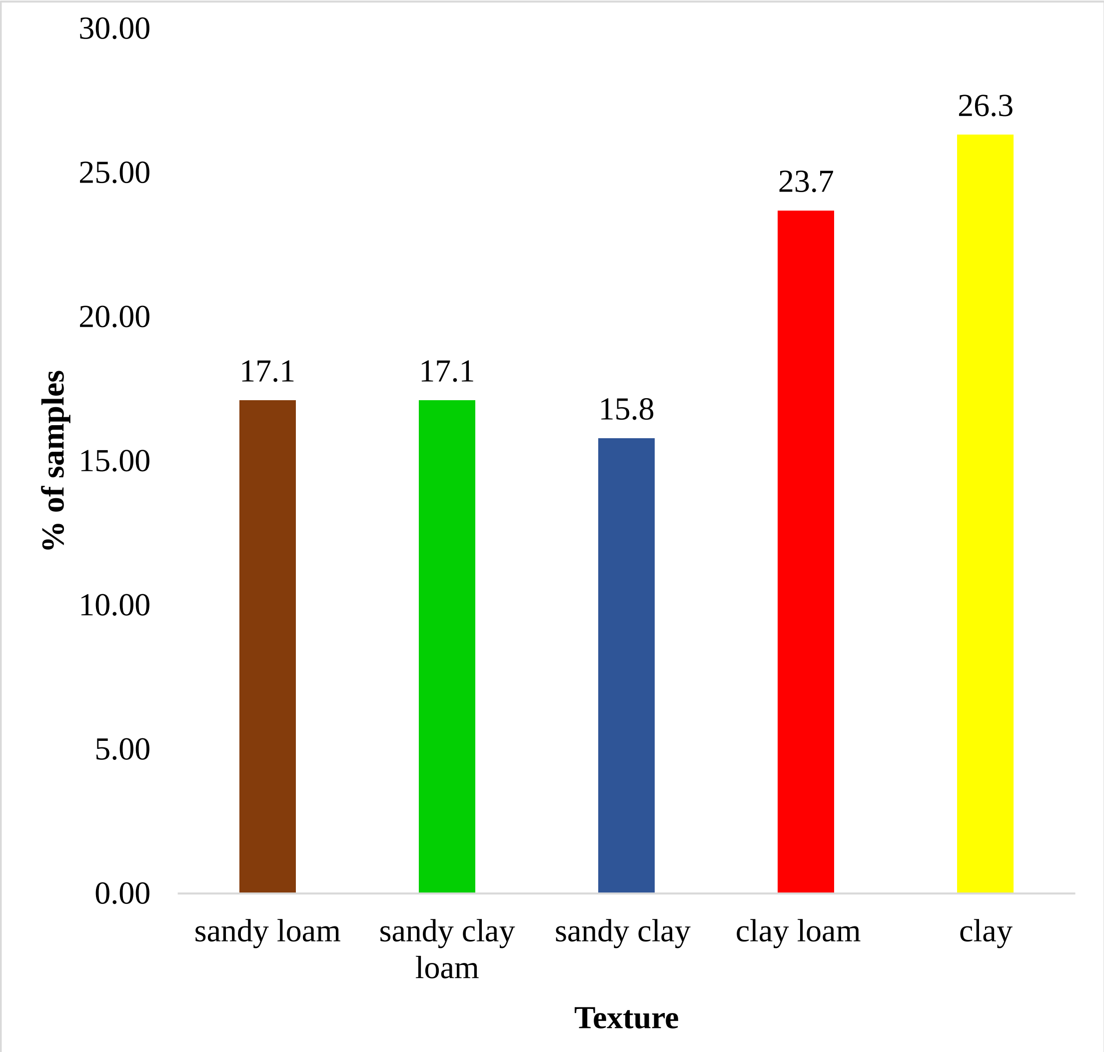

Fig 6. Frequency distribution of soil texture in the post-flood soils of AEU 16 in Idukki district

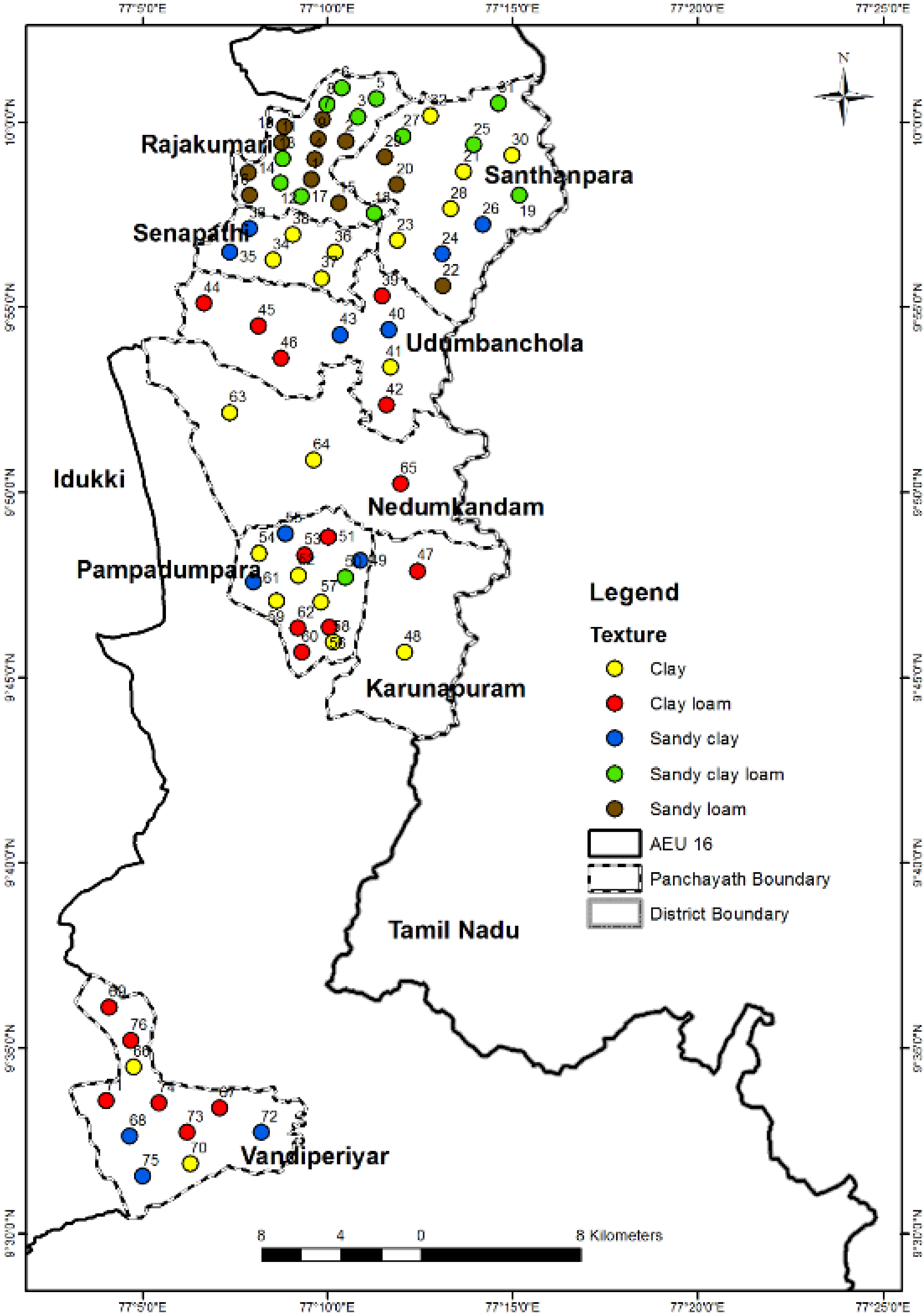

Fig 7. Spatial distribution of texture in the post-flood soils of AEU 16 in Idukki district

5.1.5. Soil moisture

The soil moisture content of post-flood soils of AEU ranged from 3.10 (Rajakumari) to 50.6% (Rajakumari). Percentage soil moisture content of about 28.9 per cent of soil samples were of less than 10 %. For 27.6 per cent of samples, it ranged from 10 to 15 %, for another 17.1 per cent samples it was from 15 to 25% and 26.3 per cent had soil moisture content greater than 25% (Fig 8). The highest mean value of soil moisture content was observed in Vandiperiyar panchayath which may be due to higher organic carbon content and predominance of clay in soils having moderately fine to fine textured clayey soils.

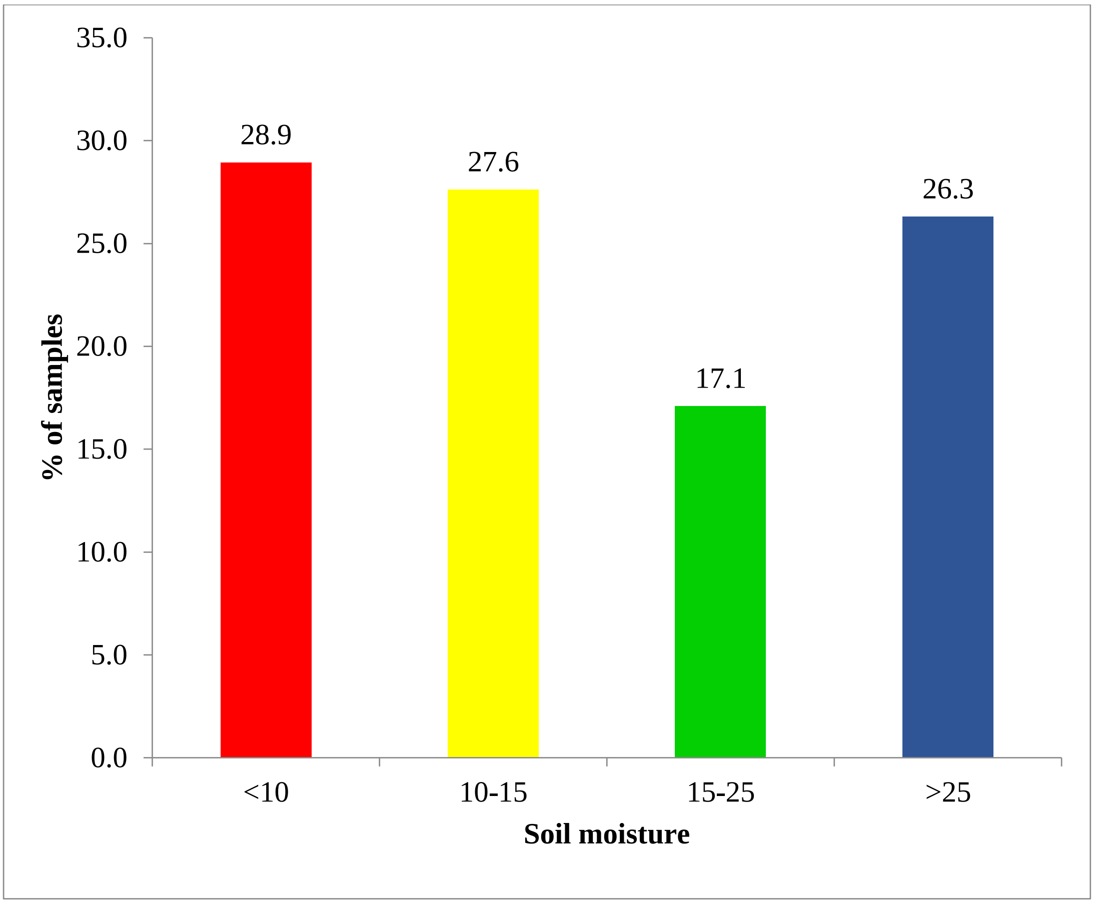

Fig 8. Frequency distribution of soil moisture (%) in the post-flood soils of AEU 16 in Idukki district

5.1.6. Water holding capacity

The water holding capacity of post-flood soils of AEU ranged from 30.1 (Santhanpara) to 73.5% (Vandiperiyar). About 79.0 per cent of soil samples had water holding capacity ranged from 30 to 50%, for 18.4 per cent it ranged from 50 to 70% and for another 2.63 per cent samples, it was greater than 70% (Fig 9). The highest mean of water holding capacity was found in Vandiperiyar panchayath due to porous and fine textured nature of soil. Water holding capacity was found to be more for soils with lesser value of bulk density and showed a significant negative correlation (Table 23).

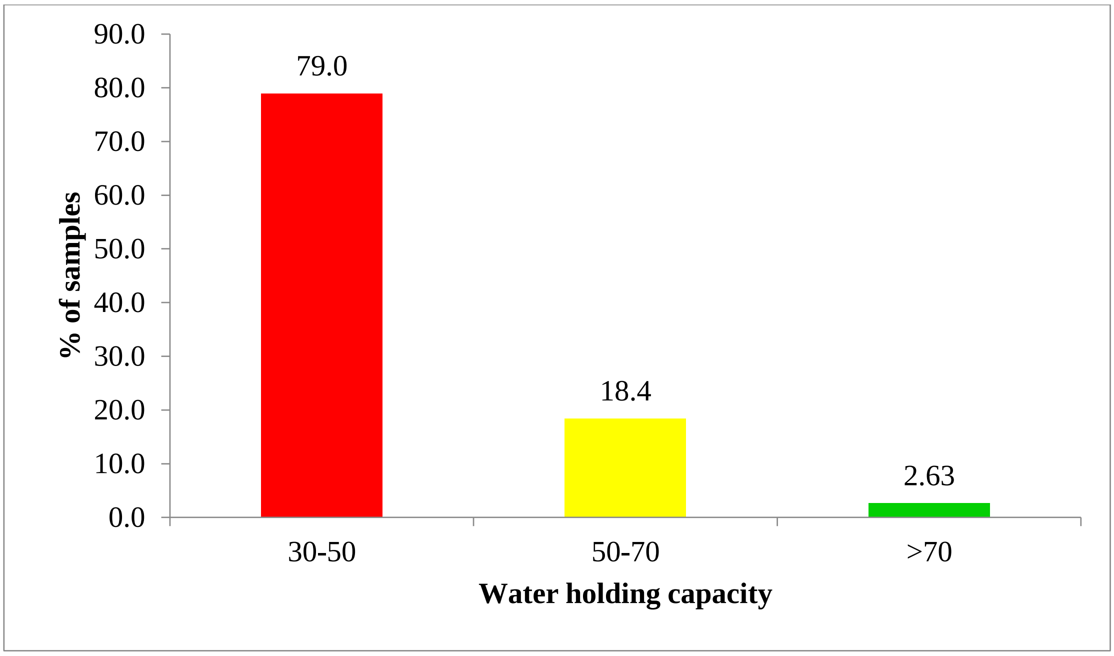

Fig 9. Frequency distribution of water holding capacity (%) in the post-flood soils of AEU 16 in Idukki district of Kerala

5.1.7. Water stable aggregates

The water stable aggregates of post-flood soils of AEU ranged from 33.8 (Vandiperiyar) to 92.4 % (Rajakumari). About 1.30 per cent of soil samples had water stable aggregates ranged from 30 to 50 %, 59.2 per cent ranged from 50 to 70 % and 39.5 per cent had water sable aggregates greater than 70 % (Fig. 10).

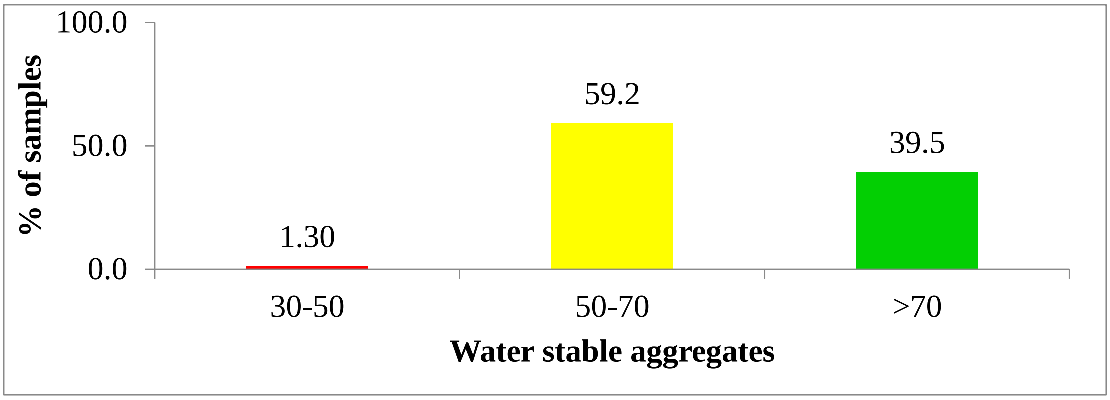

Fig 10. Frequency distribution of water stable aggregates (%) in the post-flood soils of AEU 16 in Idukki district

5.1.8. Mean weight diameter

The mean weight diameter of post-flood soils of AEU ranged from 0.30 (Vandiperiyar) to 2.62 mm (Pampadumpara). About 72.4 per cent of soil samples had a mean weight diameter of less than 1 mm, 18.4 per cent ranged from 1.0 to 1.5 mm, 3.95 per cent ranged from 1.5 mm to 1.5 mm (Fig 11). The land use had a significant effect on the stability and size distribution of soil aggregates. Lowland areas where paddy was cultivated showed highest MWD, and upland had the lowest MWD (Wang *et al.*, 2019).

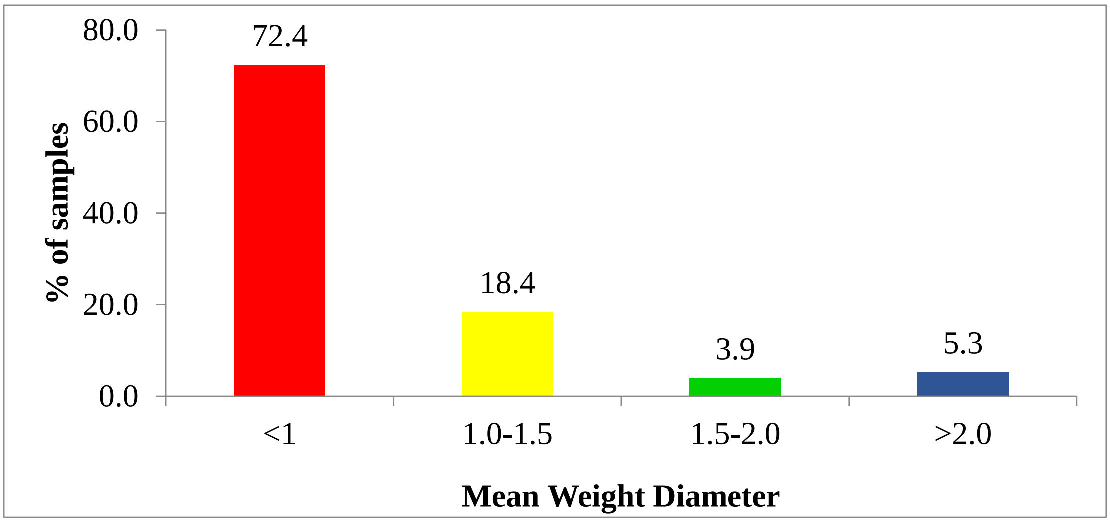

Fig.11 Frequency distribution of mean weight diameter (mm) in the post-flood soils of AEU 16 in Idukki district of Kerala

5.2. Chemical attributes

5.2.1. Soil pH

The pH of post-flood soils of AEU ranged from 4.62 (Rajakumari) to 6.92 (Santhanpara). The mean value of pH in the AEU was found to be 5.78.

A comparison of soil fertility status in the pre-flood and post-flood scenario is presented in Appendix III. About 17.1 per cent of soil samples were found to be very strongly acidic as well as strongly acidic, 22.4 per cent were moderately acidic, 30.3 per cent were slightly acidic and 13.2 per cent in neutral range of pH (Fig 12). On the contrary, 6.88 per cent of samples were extremely acidic, 29.0 per cent very strongly acidic, 29.8 per cent strongly acidic, 21.8 per cent moderately acidic, 11.3 per cent slightly acidic and 1.50 per cent had a neutral pH in the pre-flood scenario (GOK, 2013).The increase in pH might be due to the sedimentation of some basic cations at the surface. The presence of organic deposits at the surface might have prevented the production of organic acids which led to an increase in pH (KSBB, 2019). Spatial distribution of pH in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 13.

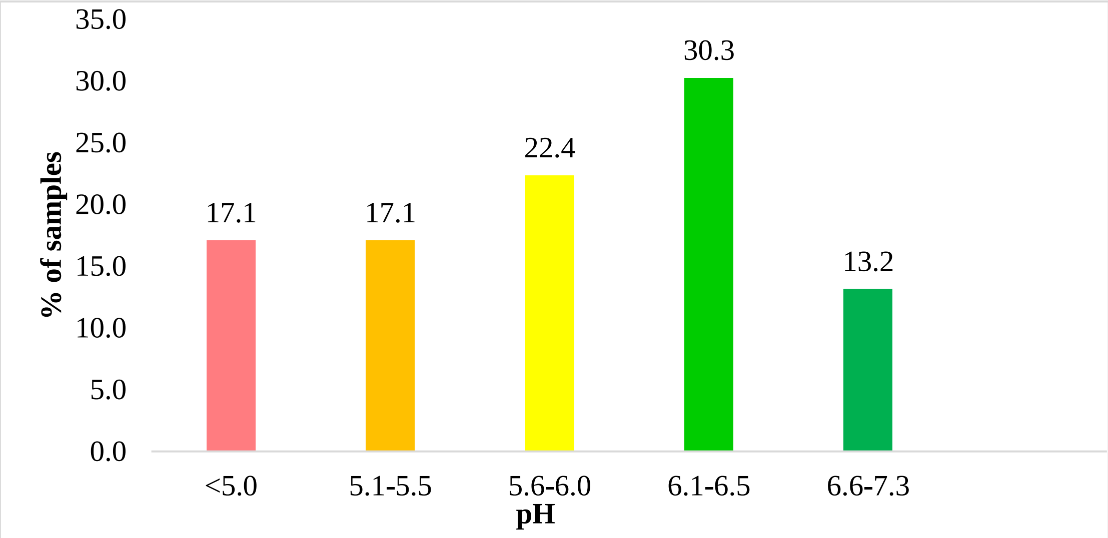

Fig 12. Frequency distribution of pH in the post-flood soils of AEU 16 in Idukki district

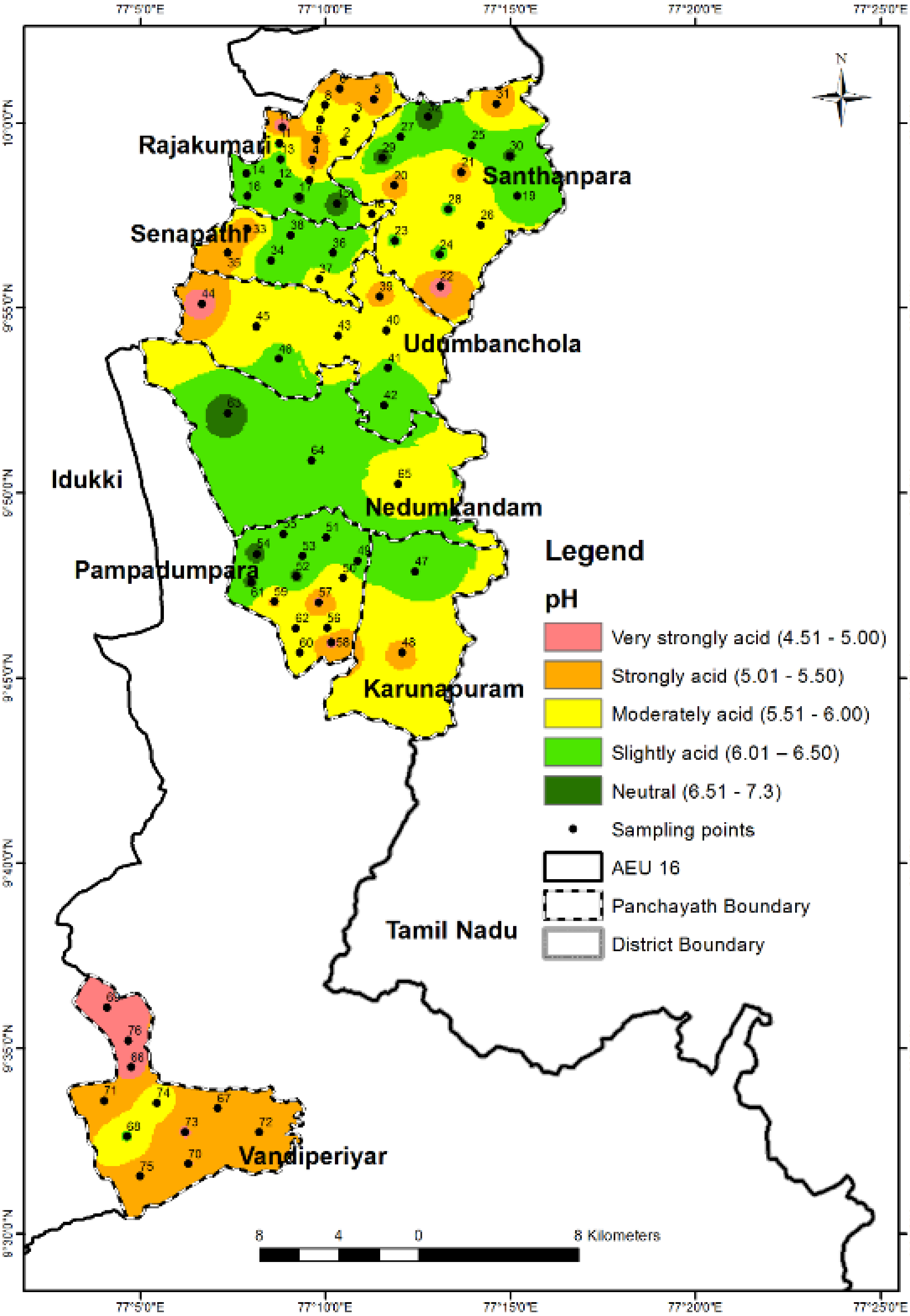

Fig 13. Spatial distribution of pH in the post-flood soils of AEU 16 in Idukki district.

5.2.2. Electrical conductivity

The EC of post-flood soils of AEU ranged from 0.04 (Santhanpara and Pampadumpara) to 0.52 dS m^{-1}(Santhanpara). The mean value of EC in the AEU was found to be 0.16 dS m^{-1}. Flooding increased the dilution of soil, thereby increasing pH and decreasing electrical conductance indicating the absence of soluble ions at the soil surface (Ponnamperuma, 1984). All the soil samples analysed for electrical conductivity was found to be in the range less than 1.0 dS m^{-1}(Fig 14).

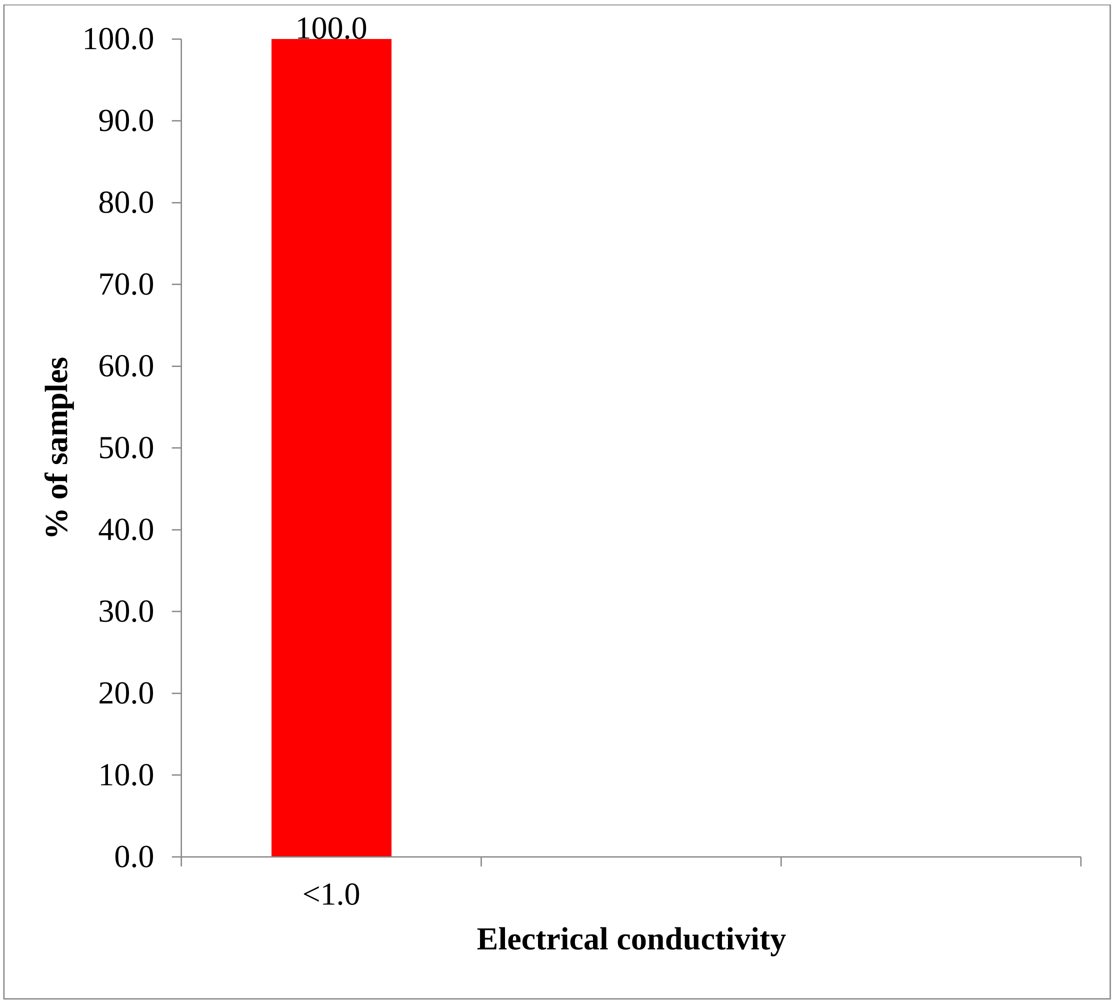

Fig 14. Frequency distribution of electrical conductivity (dS m^{-1}) in the post-flood soils of AEU 16 in Idukki district

5.2.3. Organic carbon

The organic carbon content of post-flood soils of AEU ranged from 0.63 (Santhanpara) to 4.68% (Rajakumari). The mean value of organic carbon in the AEU was found to be 2.35%. About 14.5 per cent of samples had medium organic carbon and 85.5 per cent had high organic carbon content (Fig 15). On the contrary, about 4.75 per cent, 26.4 per cent and 68.8 per cent of soil samples in the AEU had low, medium and high organic carbon content in the pre-flood scenario (GOK, 2013). Hence, there is an increase in the organic carbon status after flooding which may be due to the deposition of organic sources and slow mineralization of organic matter. Organic carbon content increased in the mountainous, highland and upland regions (KSBB, 2019). The sampling sites were undulating and rolling terrain. However, altitude and slope of the sites were not recorded at the time of sampling. Spatial distribution of organic carbon in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 16.

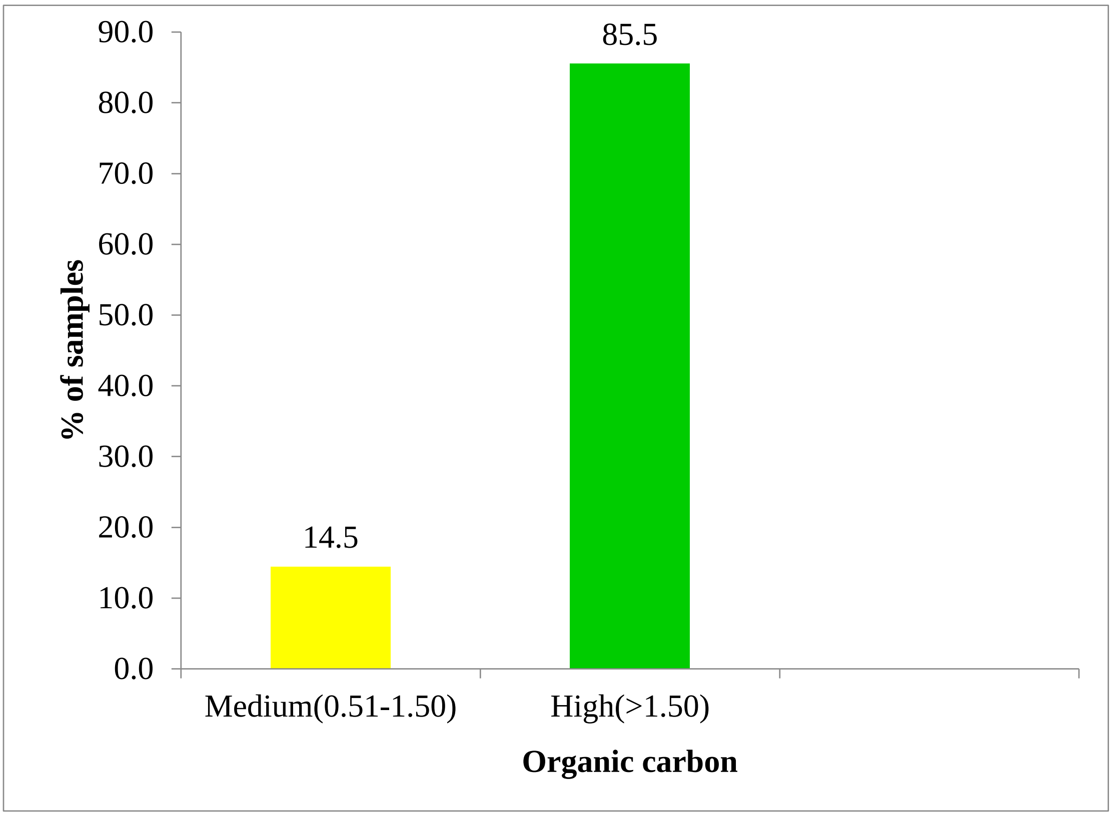

Fig 15. Frequency distribution of organic carbon (%) in the post-flood soils of AEU 16 in Idukki district

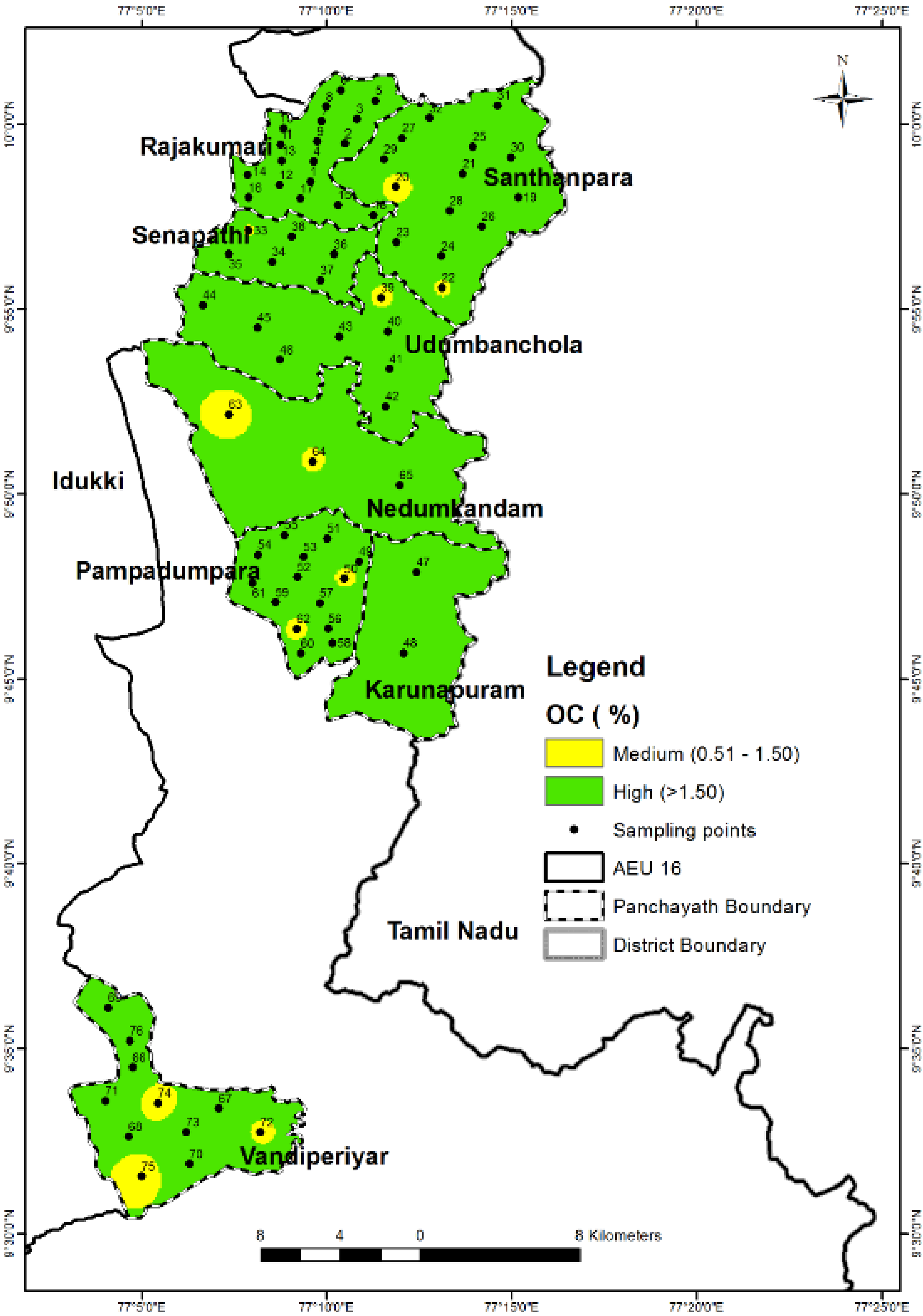

Fig 16. Spatial distribution of organic carbon in the post-flood soils of AEU 16 in Idukki district.

5.2.4. Available Nitrogen

The available N of post-flood soils of AEU ranged from 151 (Senapathi) to 389 kg ha^{-1}(Pampadumpara). The mean value of available N in the AEU was found to be 247 kg ha^{-1}. About 77.6 per cent of soil samples showed a low range and 22.4 per cent showed a medium range of available N (Fig 17). Low available N content in spite of high organic carbon may be due to crop removal and nutrient losses by leaching. Slow decomposition of organic matter amidst the sedimented soil could be the reason for low available N. Spatial distribution of available N in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 18.

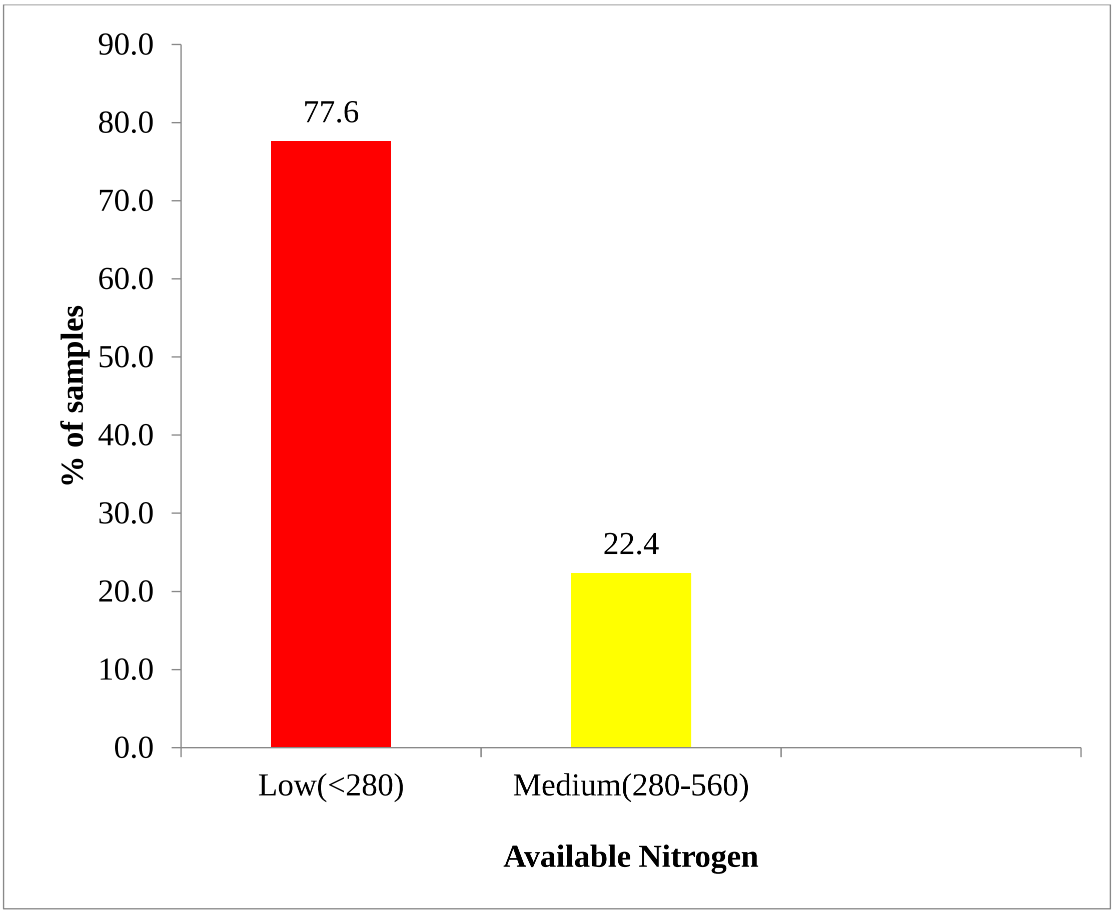

Fig 17. Frequency distribution of available N (kg ha^{-1}) in the post-flood soils of AEU 16 in Idukki district of Kerala

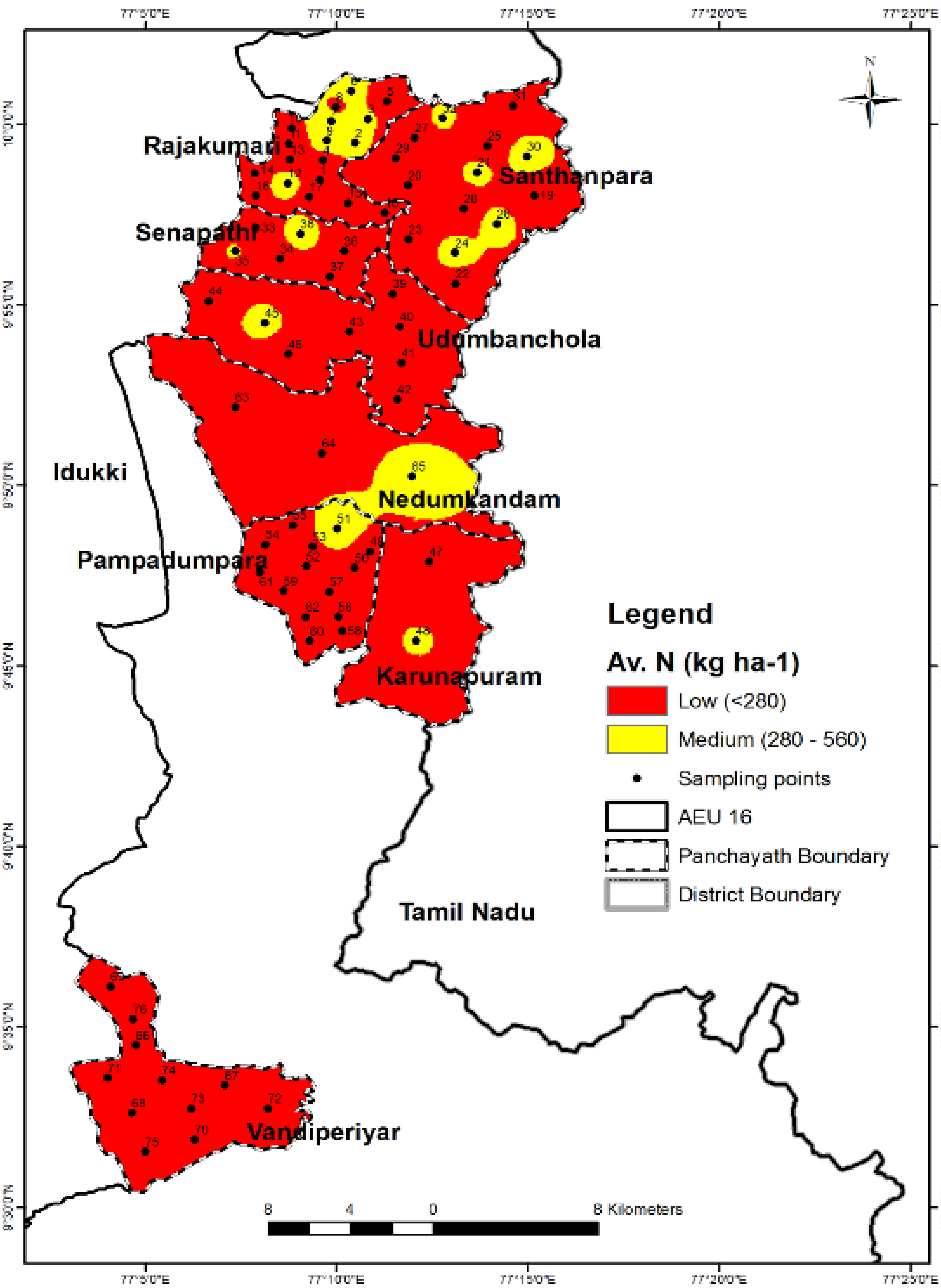

Fig 18. Spatial distribution of available N in the post-flood soils of AEU 16 in Idukki district

5.2.5. Available phosphorous

The available P of post-flood soils of AEU ranged from 2.90 (Nedumkandam) to 191 kg ha^{-1}(Pampadumpara). The mean value of available P in the AEU was found to be 42.0 kg ha^{-1}. About 22.4 per cent, 23.7 per cent and 53.9 per cent of soil samples had low, medium and high available P respectively (Fig 19). Application of phosphatic fertilizers would have led to an increase in phosphorous content of soils. However, about 27.9 per cent, 25.8 per cent and 46.4 per cent of soil samples in the AEU had low, medium and high available P in the pre-flood scenario (GOK, 2013). Spatial distribution of available P in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 20.

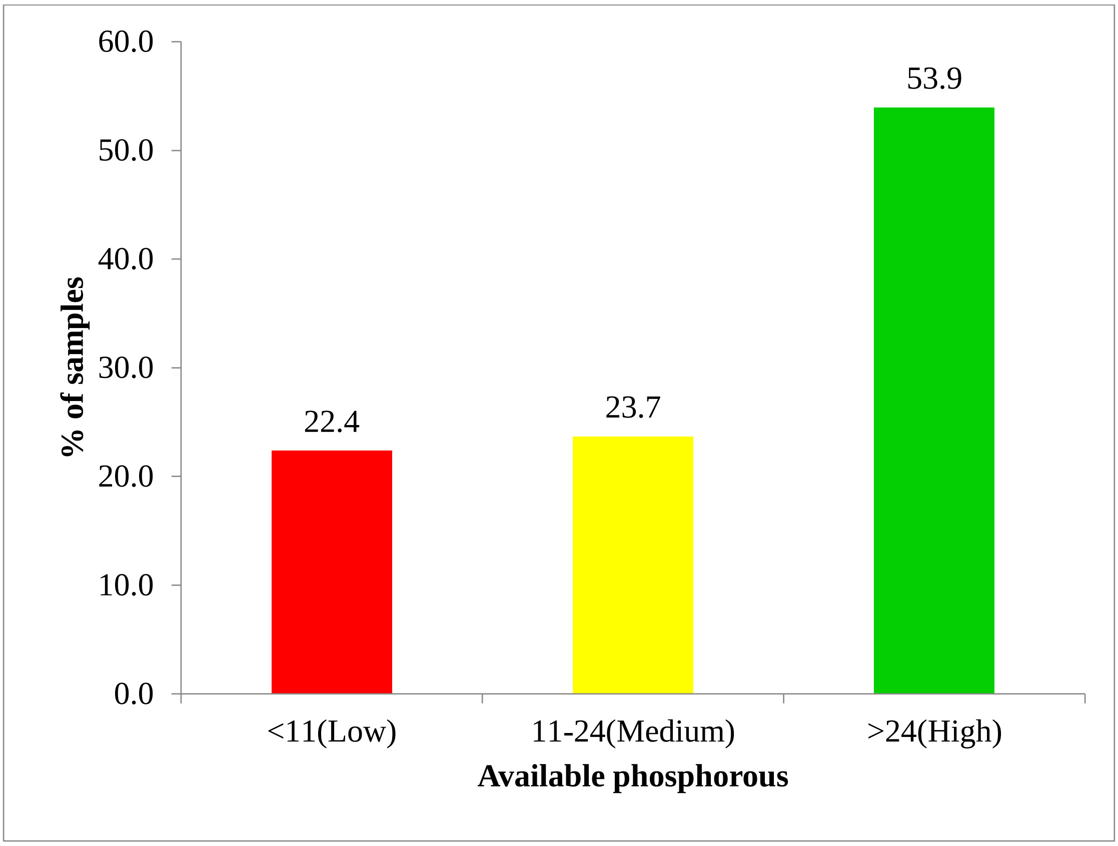

Fig 19. Frequency distribution of available P (kg ha^{-1}) in the post-flood soils of AEU 16 in Idukki district

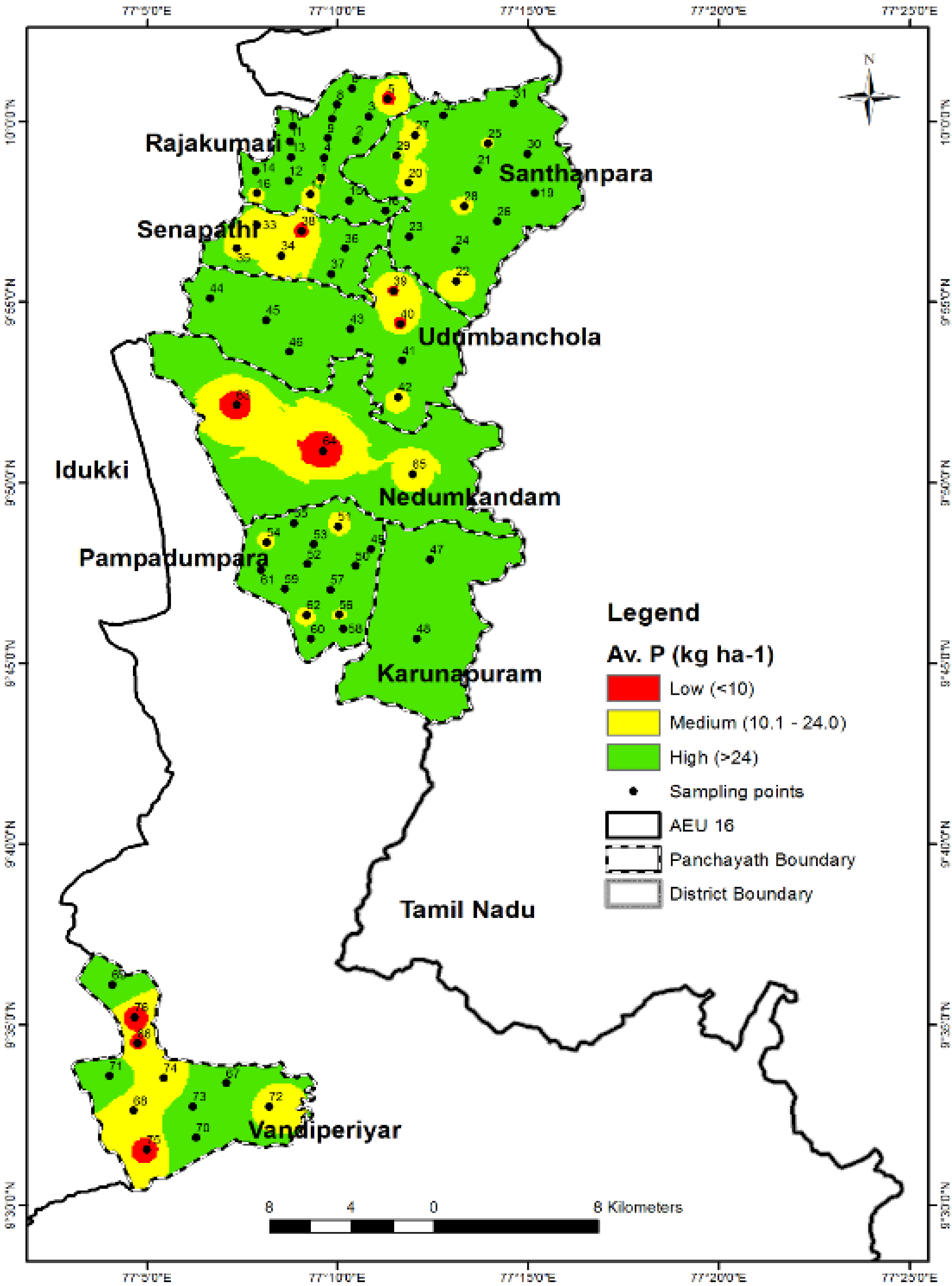

Fig 20. Spatial distribution of available P in the post-flood soils of AEU 16 in Idukki district.

5.2.6. Available potassium

The available K of post-flood soils of AEU ranged from 22.4 (Santhanpara) to 1725 kg ha^{-1}(Karunapuram). The mean value of available K in the AEU was found to be 574 kg ha^{-1}. The increase in the available K status observed at different sampling sites in the highland and upland terrains might be due to the accumulation of K bearing minerals or exposure of K bearing minerals from below (KSBB, 2019). About 5.26 per cent, 14.5 per cent and 80.3 per cent of soil samples had low, medium and high available K respectively (Fig 21). On the contrary, about 13.1 per cent, 25.0 per cent and 61.9 per cent of soil samples in the AEU had low, medium and high available potassium in the pre-flood scenario (GOK, 2013). Spatial distribution of available K in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 22.

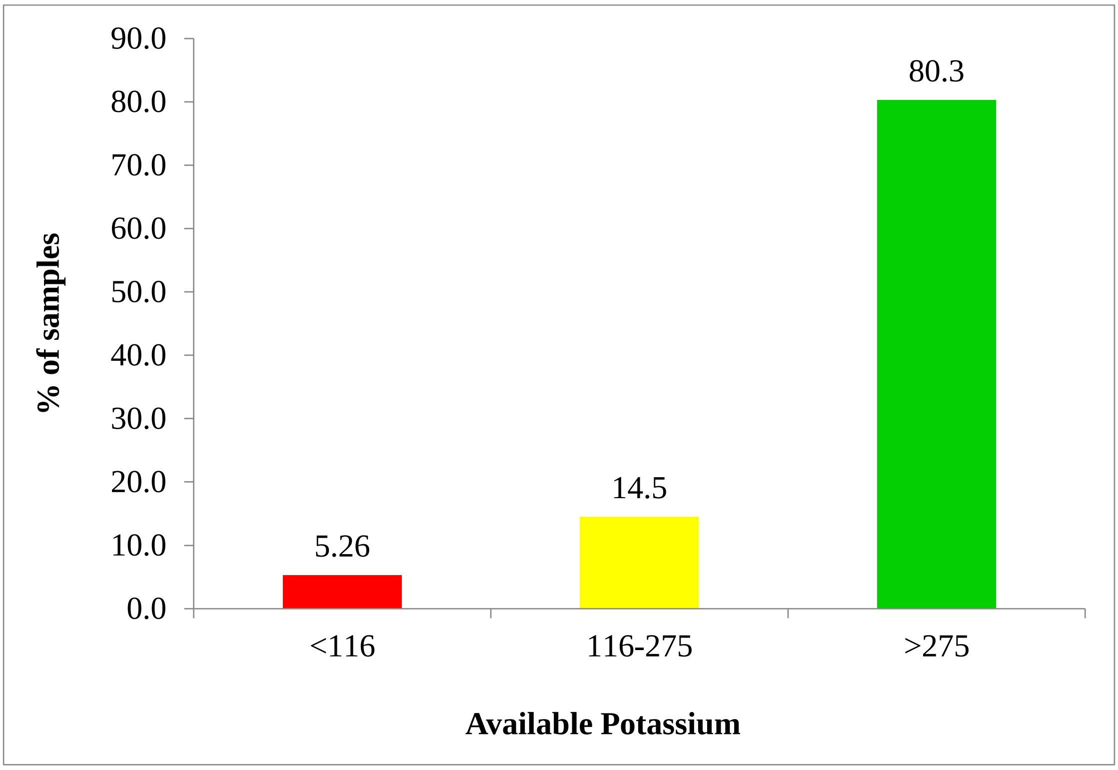

Fig 21. Frequency distribution of available K (kg ha^{-1}) in the post-flood soils of AEU 16 in Idukki district

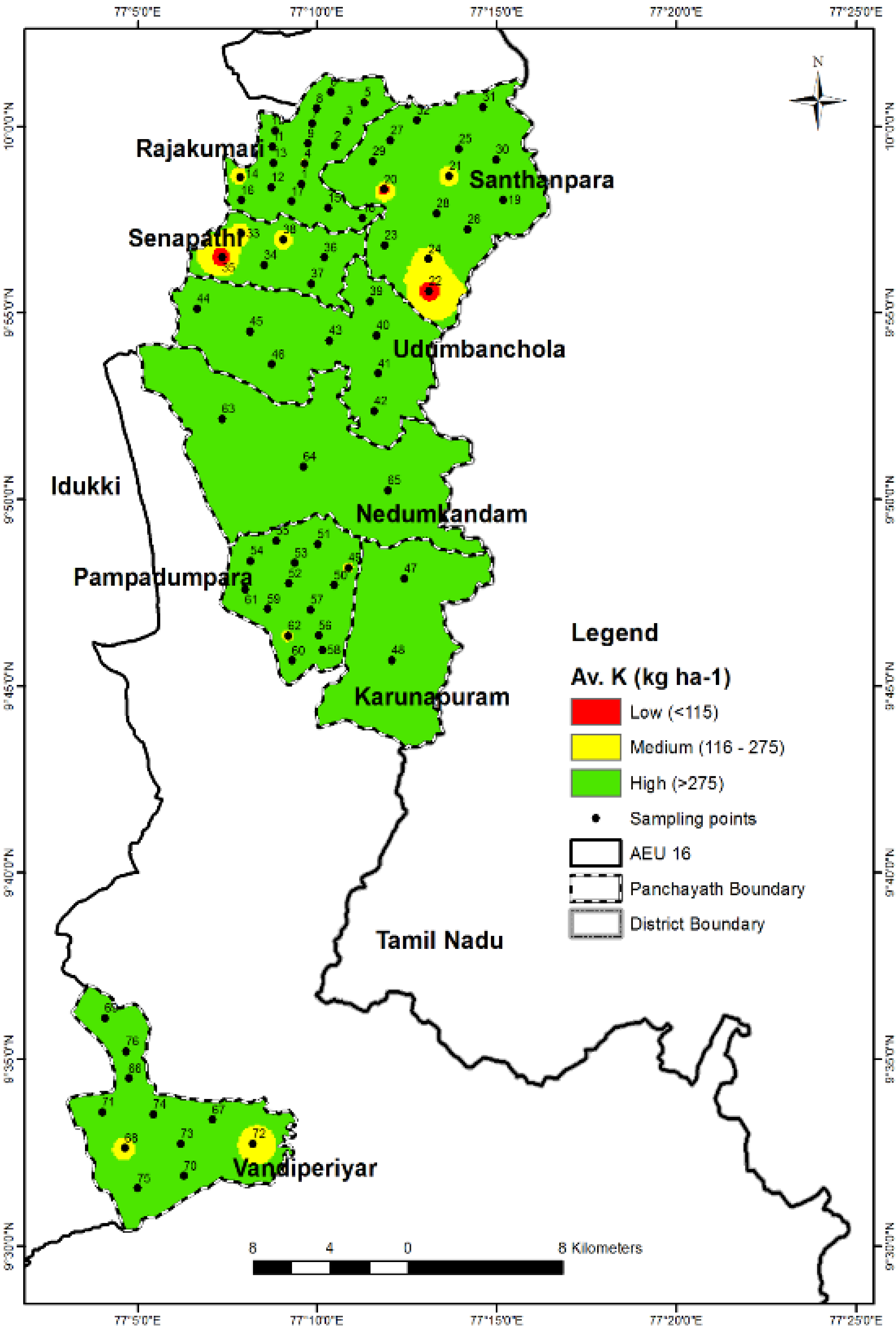

Fig 22. Spatial distribution of available K in the post-flood soils of AEU 16 in Idukki district

5.2.7. Available calcium

The available Ca of post-flood soils of AEU ranged from 120 mg kg^{-1} (Vandiperiyar) to 1480 mg kg^{-1}(Santhanpara). The mean value of available Ca in the AEU was found to be 847 mg kg^{-1}. Application of liming materials like lime and dolomite would have led to an increase in Ca content of soil. About 6.58 per cent of soil samples were found to be deficient and 93.4 per cent adequate in available Ca (Fig 23). However, about 12.3 per cent of soil samples were deficient and 87.8 per cent adequate in available Ca in the pre-flood scenario (GOK, 2013). Spatial distribution of available Ca in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 24.

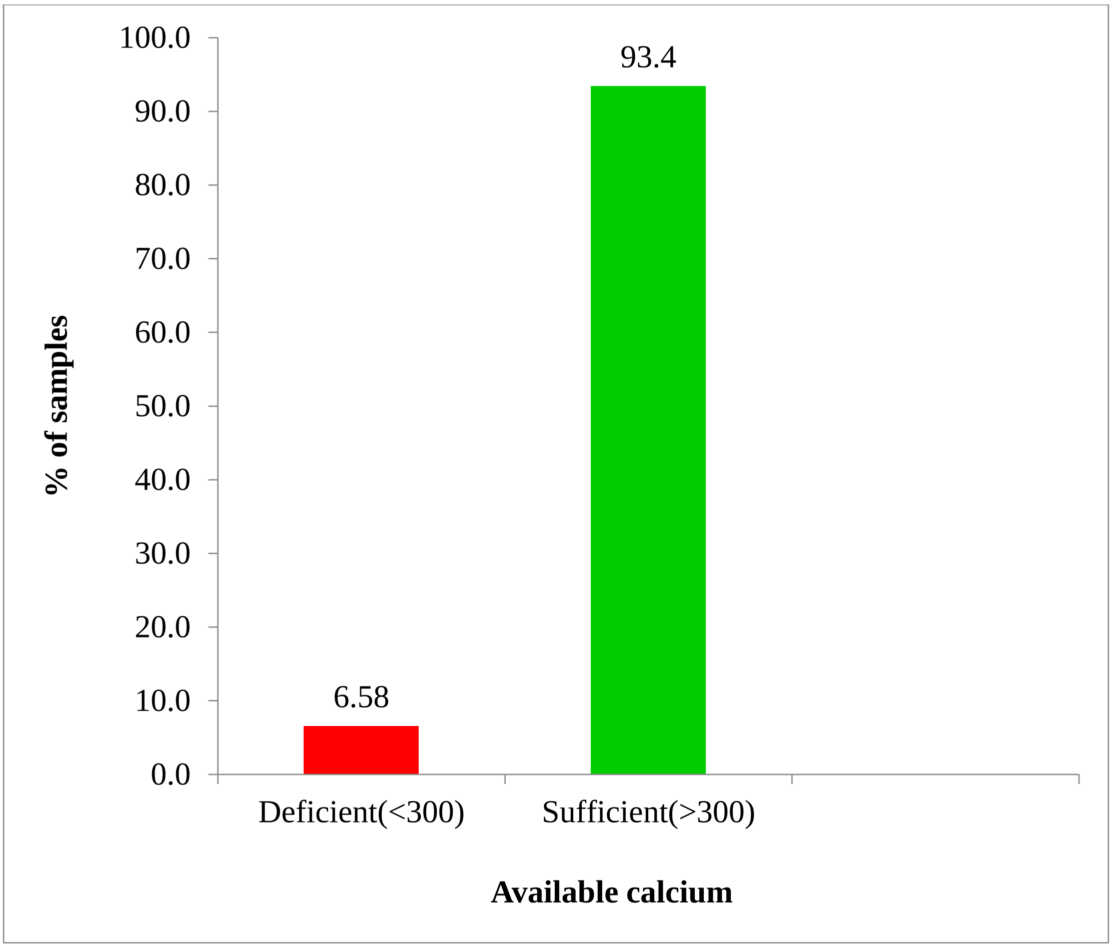

Fig 23. Frequency distribution of available Ca (mg kg^{-1}) in the post-flood soils of AEU 16 in Idukki district

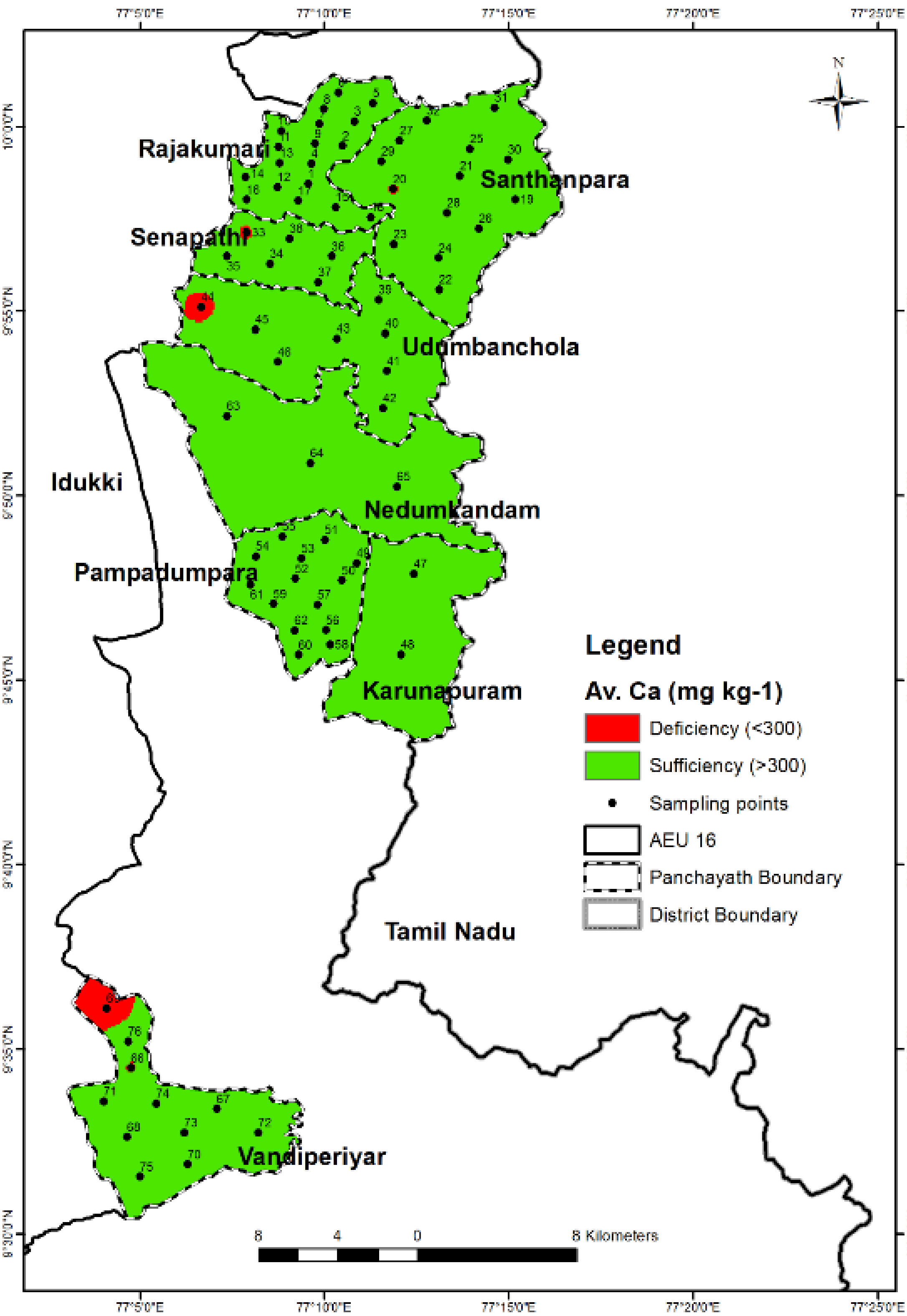

Fig 24. Spatial distribution of available Ca in the post-flood soils of AEU 16 in Idukki district

5.2.8. Available magnesium

The available Mg of post-flood soils of AEU ranged from 48.0 (Udumbanchola) to 780 mg kg^{-1}(Rajakumari). The mean value of available Mg in the AEU was found to be 222 mg kg^{-1}. About 7.89 per cent of soil samples were found to be deficient and 92.1 per cent adequate in available Mg (Fig 25). Low cost as well as dual nutrient supply of dolomite (Ca and Mg) has made farmers to preferably use dolomite for liming which has increased the Mg content of soils. The flood deposits would also have contributed to the increased Mg content in soil. On the contrary, about 52.6 per cent of soil samples were deficient and 47.4 per cent adequate in available Mg in the pre-flood scenario (GOK, 2013). Spatial distribution of available Mg in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 26.

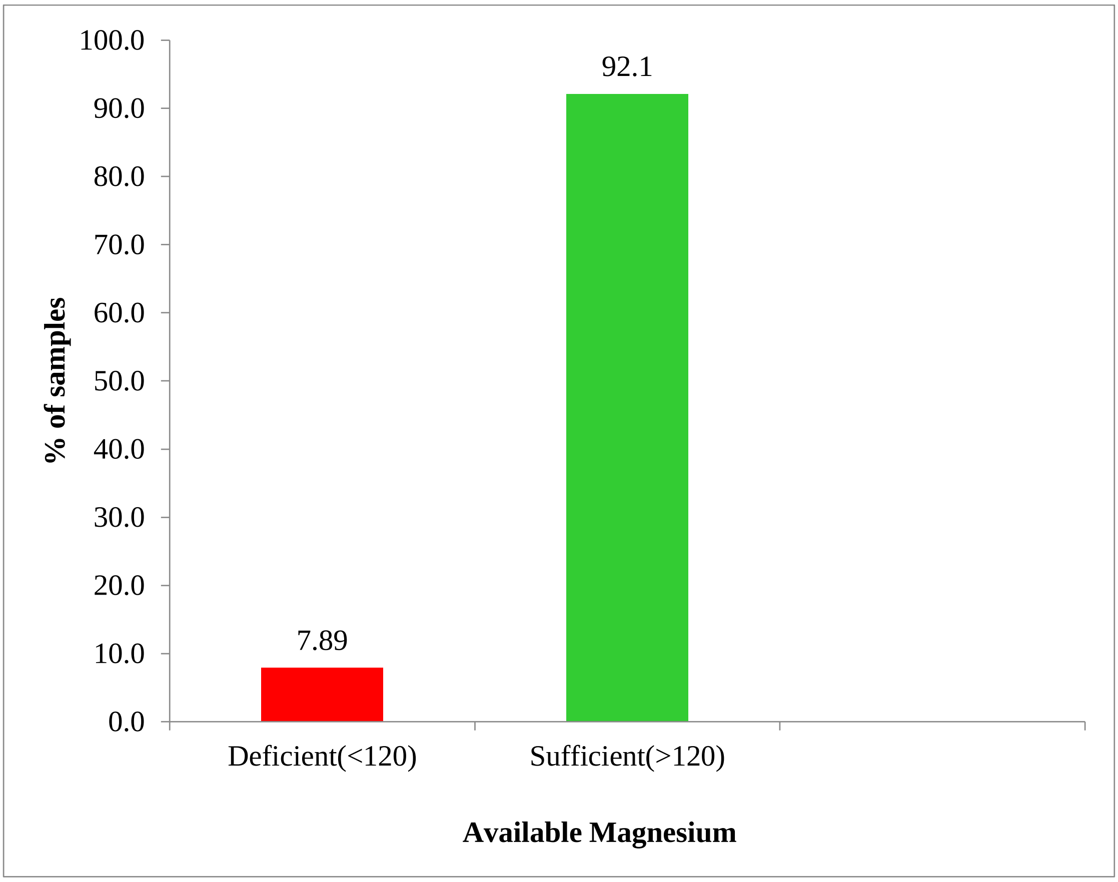

Fig 25. Frequency distribution of available Mg (mg kg^{-1}) in the post-flood soils of AEU 16 in Idukki district

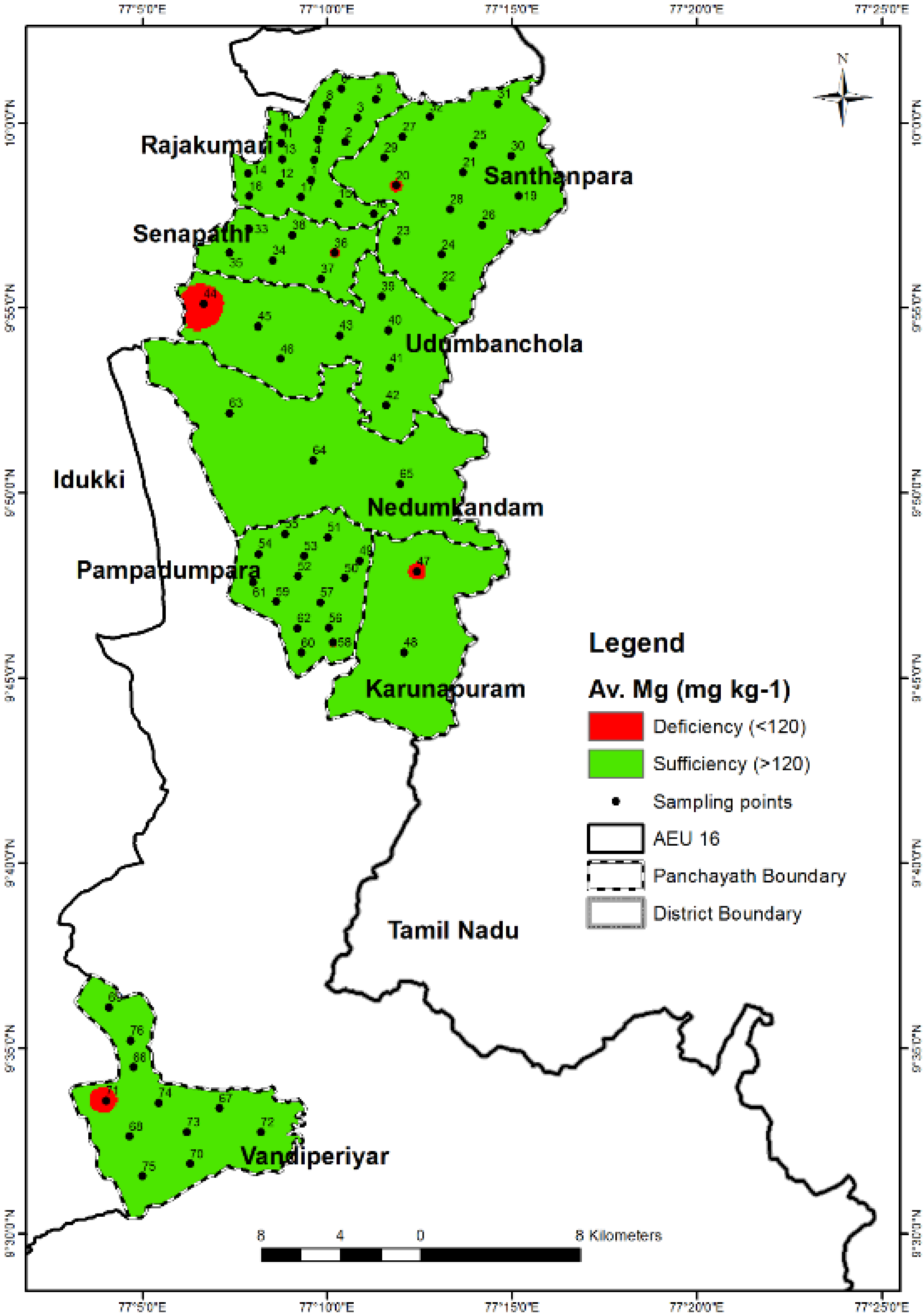

Fig 26. Spatial distribution of available Mg in the post-flood soils of AEU 16 in Idukki district

5.2.9. Available sulphur

The available S of post-flood soils of AEU ranged from 0.50 mg kg^{-1} (Pampadumpara) to 75.0 mg kg^{-1}(Rajakumari). The mean value of available S in the AEU was found to be 15.0 mg kg^{-1}. About 27.6 per cent of soil samples were found to be deficient and 72.4 per cent adequate in available S (Fig 27). On the contrary, about 71.4 per cent of soil samples were deficient and 28.6 per cent adequate in available S in the pre-flood scenario (GOK, 2013). There is a considerable change in the sulphur content of soil comparing pre- and post-flood scenario of the AEU. Spatial distribution of available S in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 29.

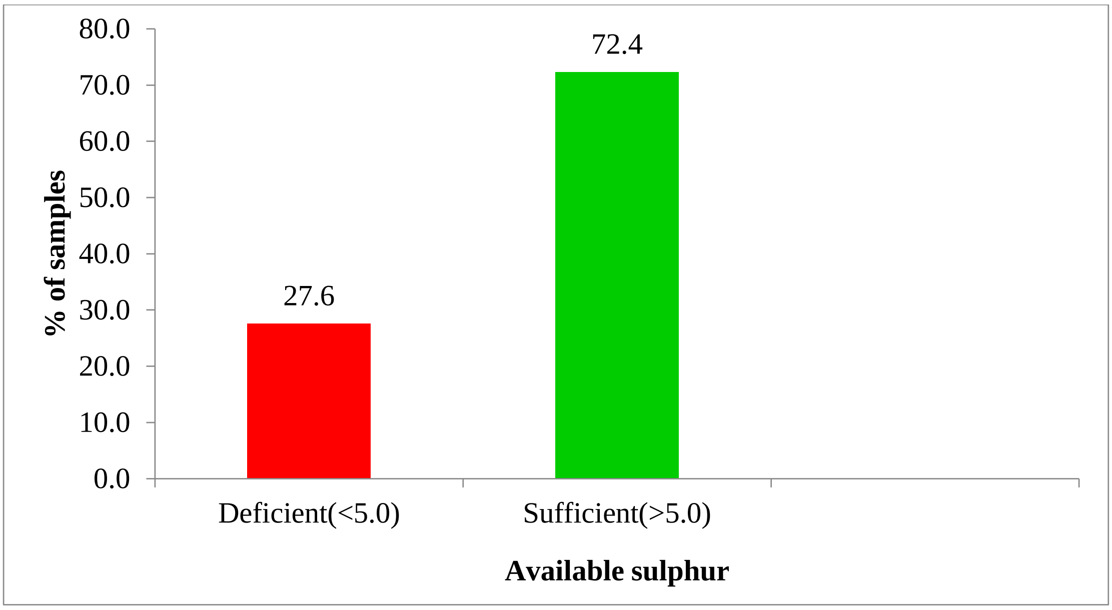

Fig 27. Frequency distribution of available S (mg kg^{-1}) in the post-flood soils of AEU 16 in Idukki district

5.2.10. Available boron

The available B of post-flood soils of AEU ranged from 0.01 mg kg^{-1} (Rajakumari and Pampadumpara) to 0.74 mg kg^{-1}(Rajakumari). The mean value of available B in the AEU was found to be 0.12 mg kg^{-1}. About 96.05 per cent of soil samples were found to be deficient and 3.95 per cent adequate in available B (Fig 28). On the contrary, about 66.6 per cent of soil samples were deficient and 33.4 per cent adequate in available boron in the pre-flood scenario (GOK, 2013). Boron content of soils showed a decrease in the post-flooded condition of AEU. Dissolution and draining off of available B in the soil (which is already deficient in status) coupled with increase in pH and higher Ca in the post-flooded condition has induced deficiency of boron in soils. Rashid and Rayan (2004) has also made similar observation. Spatial distribution of available B in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 30.

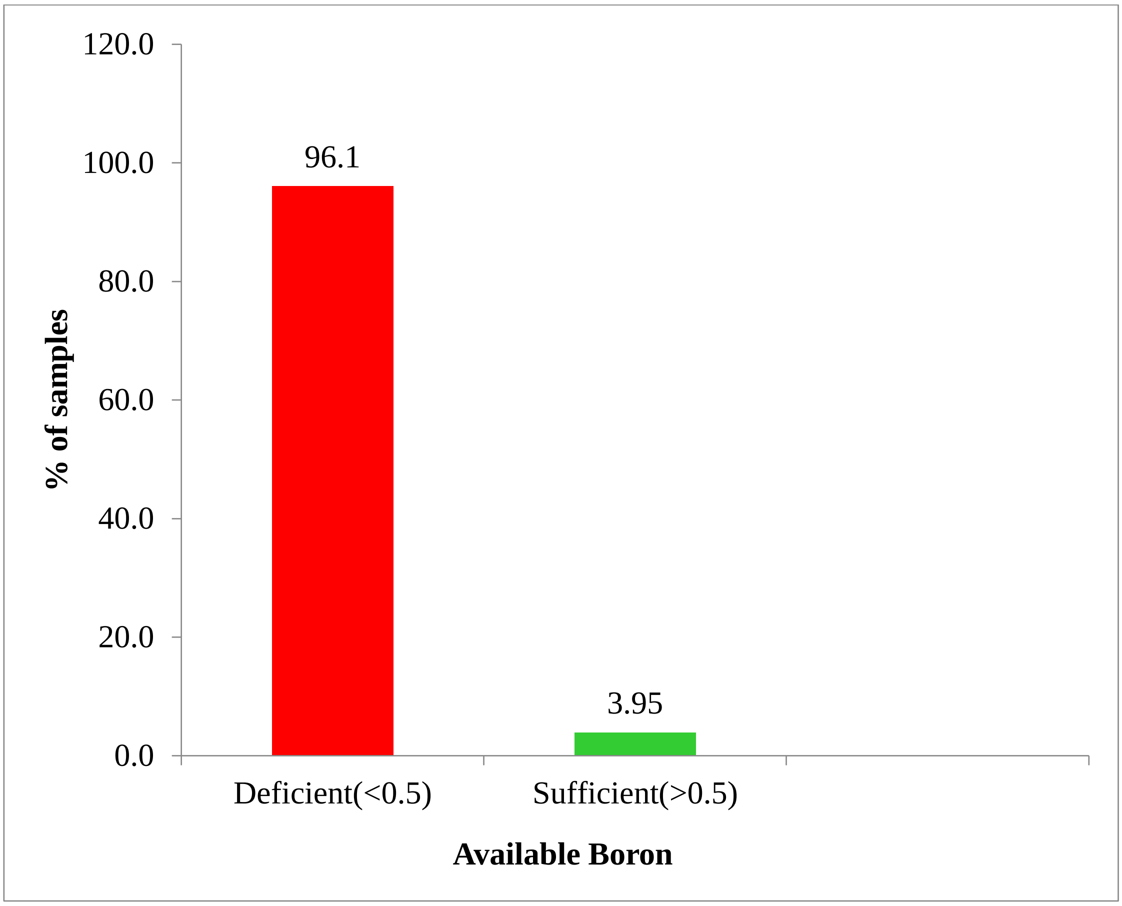

Fig 28. Frequency distribution of available B (mg kg^{-1}) in the post-flood soils of AEU 16 in Idukki district of Kerala

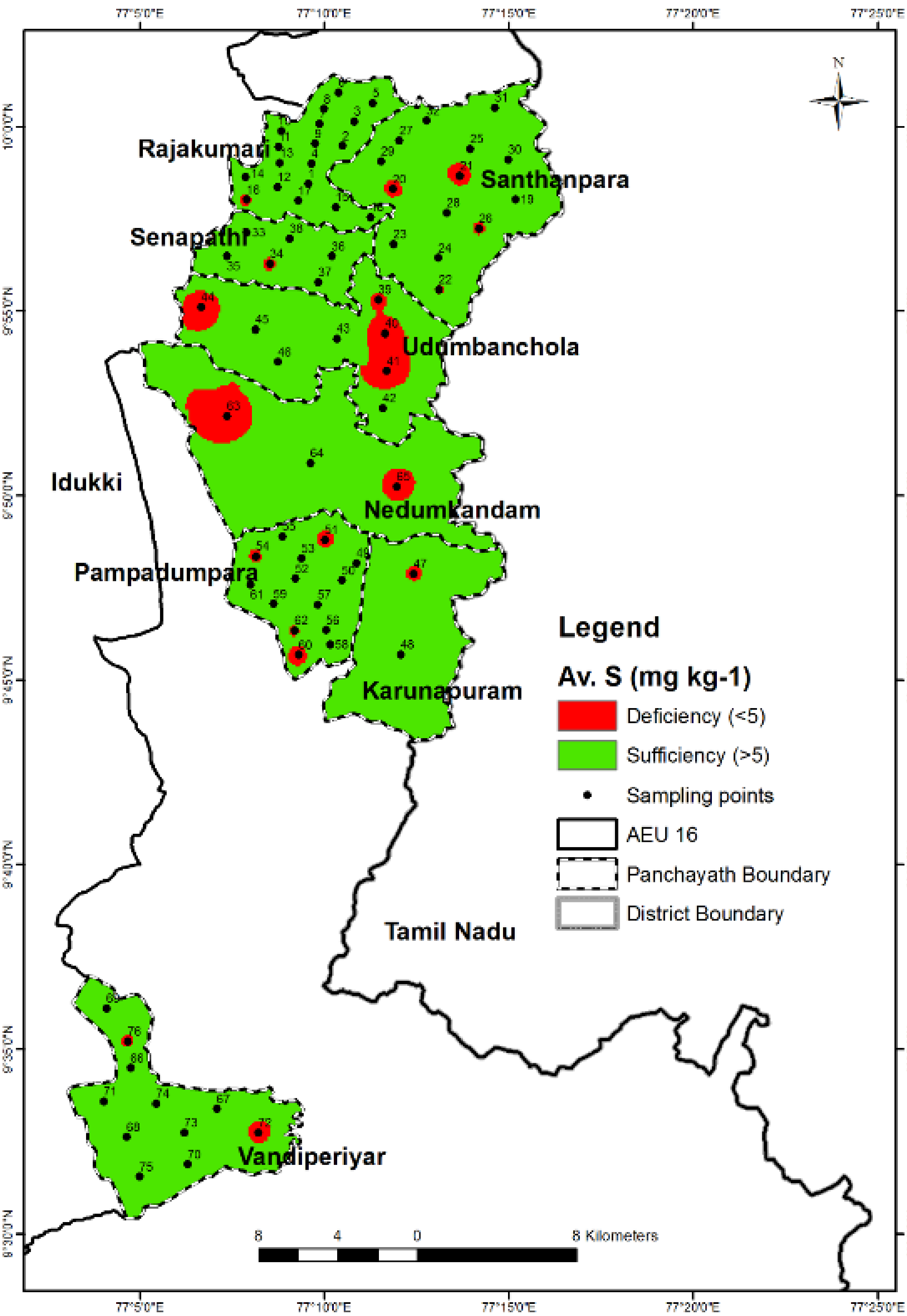

Fig 29. Spatial distribution of available S (mg kg[-1]) in the post-flood soils of AEU 16 in Idukki district

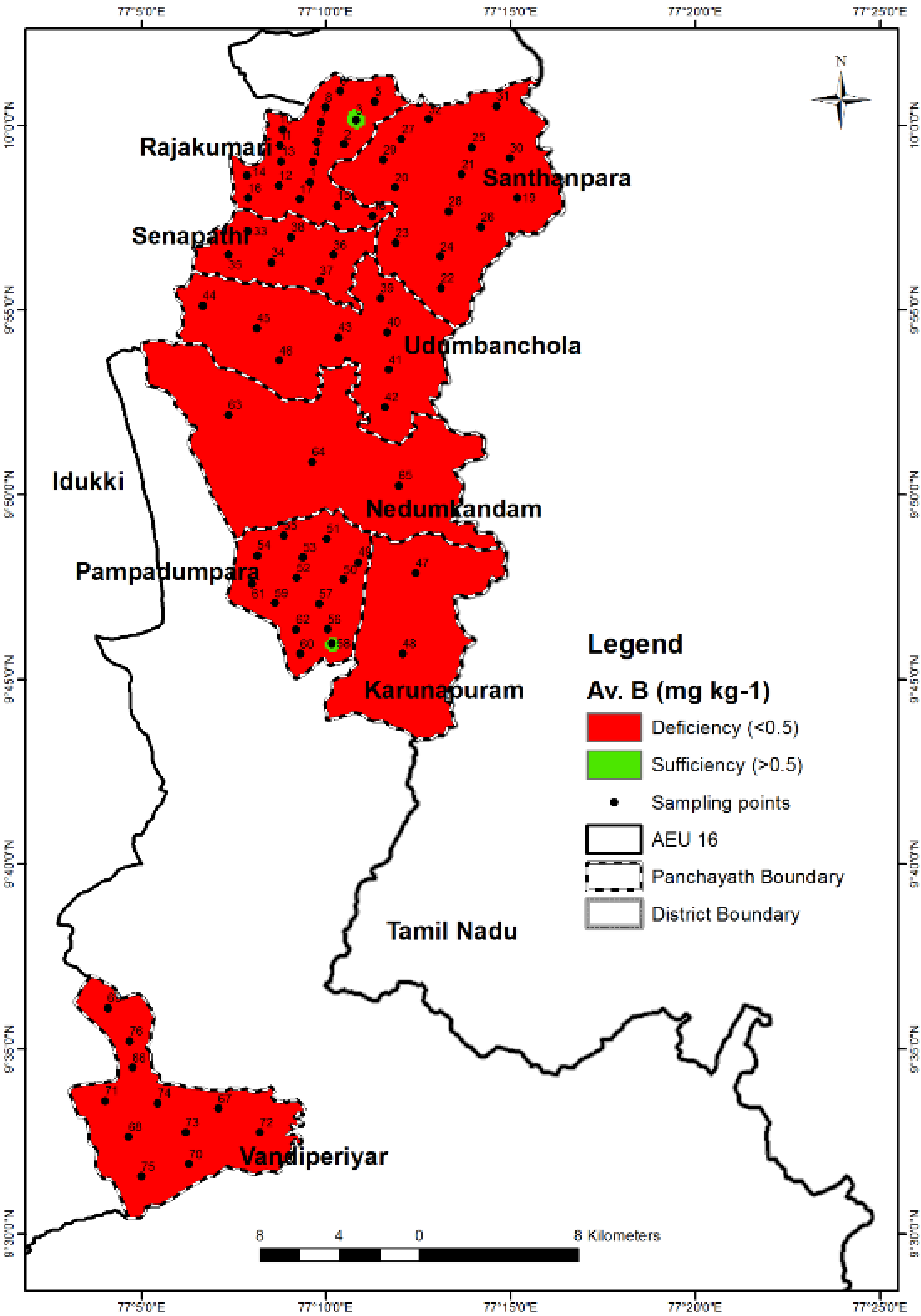

Fig 30. Spatial distribution of available B (mg kg^{-1}) in the post-flood soils of AEU 16 in Idukki district

5.3. Biological attributes

5.3.1. Acid phosphatase activity

The activity of acid phosphatase of post-flood soils of AEU ranged from 5.36 (Udumbanchola) to 85.2 µg PNP produced g soil^{-1} h^{-1} (Senapathi). The mean value of acid phosphatase activity in the AEU was found to be 29.0 µg PNP produced g soil^{-1} h^{-1}. About 5.26 per cent of soils were observed to have the activity of acid phosphatase less than 10 µg PNP produced g soil^{-1} h^{-1}, 42.1 per cent in the range of 10 to 25 µg PNP produced g soil^{-1} h^{-1}, 39.5 per cent in the range of 25 to 50 µg PNP produced g soil^{-1} h^{-1} and 13.2 per cent greater than 50 µg PNP produced g soil^{-1} h^{-1} (Fig 31). A study conducted by Kalembasa and Symanowicz (2012) reported an increase in the activity of acid phosphatase on organic fertilization. Acid phosphatase activity showed a significant positive correlation with pH organic carbon (Table 25).

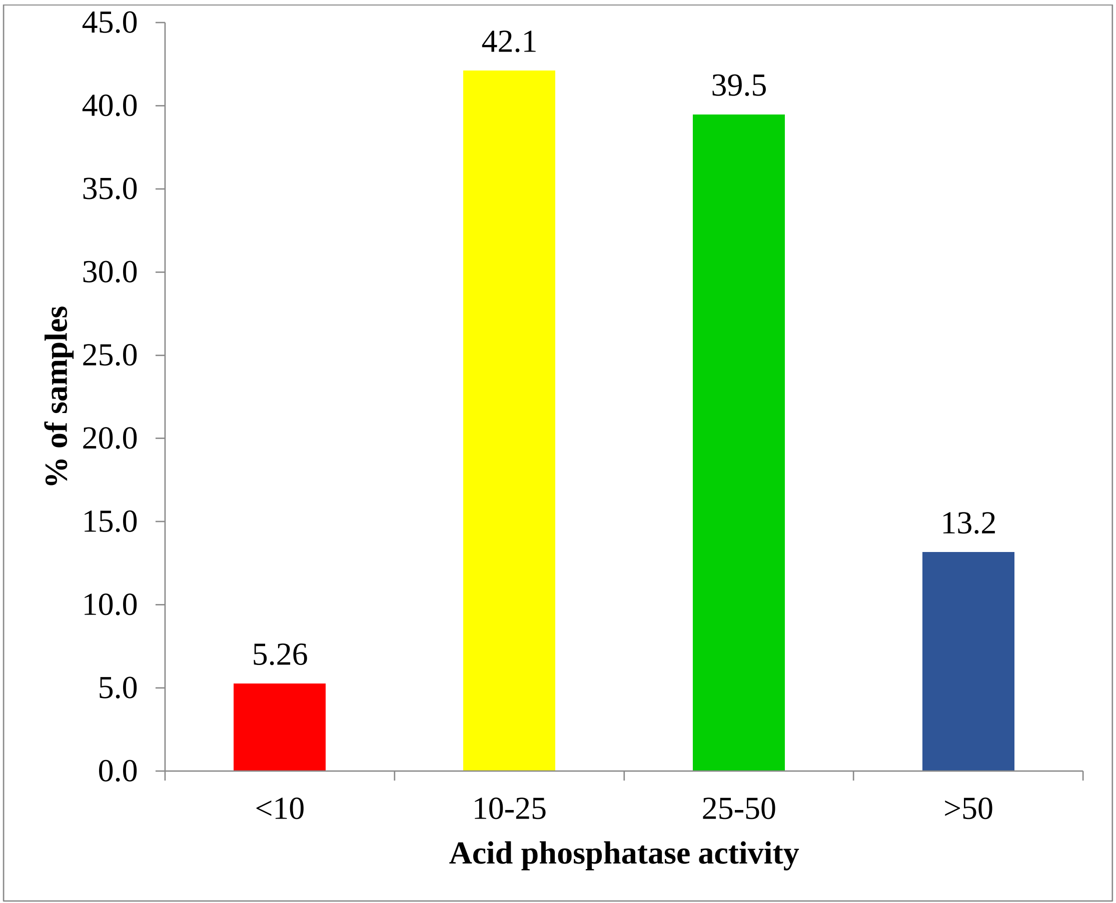

Fig 31. Frequency distribution of acid phosphatase activity (µg PNP produced g soil^{-1} h^{-1}) in the post-flood soils of AEU 16 in Idukki district

5.4. Soil quality Index

The mean of soil quality index (SQI) in post-flood soils of AEU was found to be 236. The relative soil quality (RSQI) of AEU ranged from 41.3 % (Vandiperiyar) to 73.8 % (Pampadumpara). The mean value of RSQI of AEU was 59.1 %. Principal component analysis yielded ten soil quality indicators referred as minimum data set *viz*., organic carbon, per cent clay, per cent silt, bulk density, pH, available boron, EC, available potassium, available nitrogen and soil moisture content. The soil quality index was found predominantly lower in areas where the bulk density and available potassium content is low. About 3.95 per cent, 77.6 per cent and 18.4 per cent of soil samples had low, medium and good range of relative soil quality index respectively (Fig. 32). Spatial distribution of soil quality index in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 33.

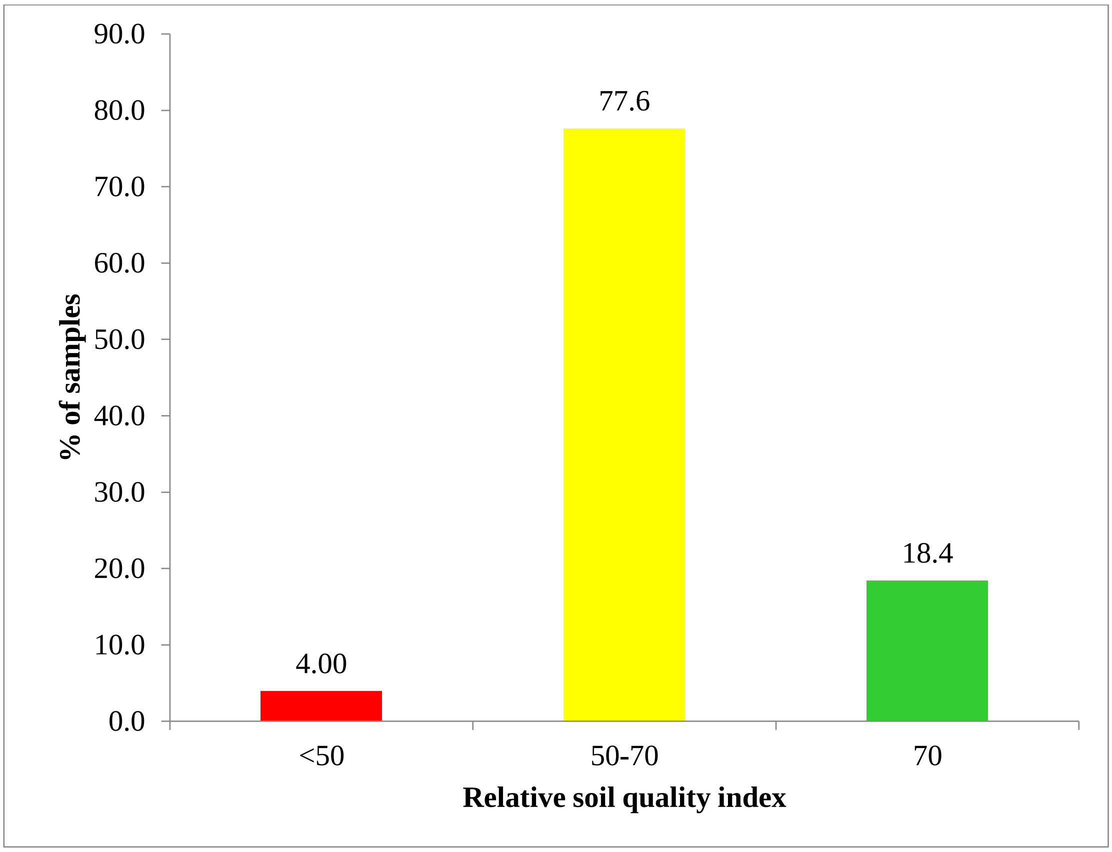

Fig 32. Frequency distribution of relative quality index (%) in the post-flood soils of AEU 16 in Idukki district

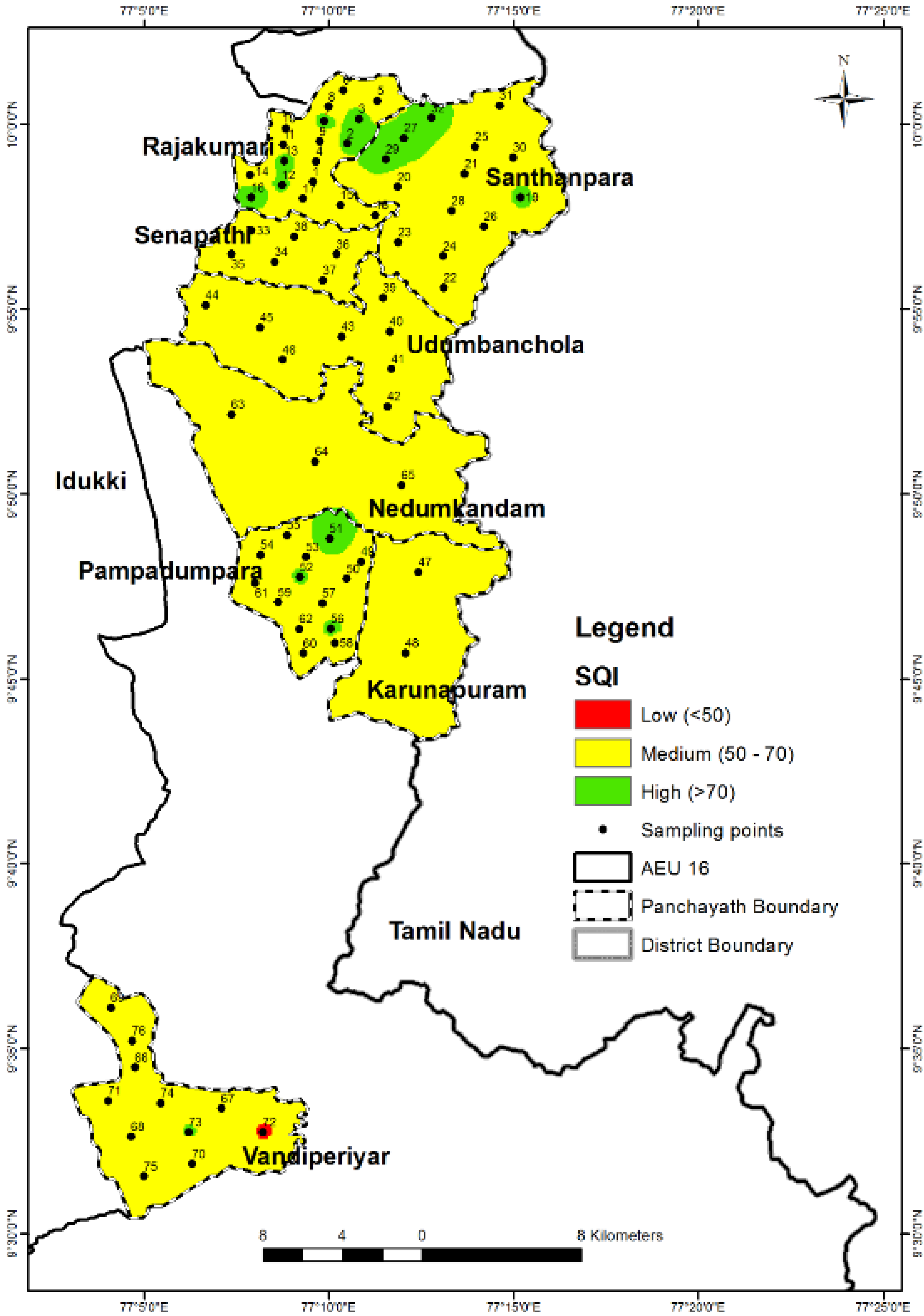

Fig 33. Spatial distribution of relative soil quality index in the post-flood soils of AEU 16 in Idukki district

5.5. Nutrient index

Nutrient index for organic carbon was high for all the panchayaths except for Nedumkandam panchayath (medium). Nutrient index for available nitrogen was low in all panchayaths. Nutrient index for available phosphorous was high in Karunapuram, Rajakumari, Santhanpara and Vandiperiyar panchayaths, was medium in Udumbanchola and Pampadumpara panchayaths and was low in Nedumkandam panchayath. Nutrient index for available potassium was high in all panchayaths except in Senapathi panchayath (medium). Spatial distribution of nutrient indices for organic carbon and available primary nutrients in the post-flood soils of AEU 16 in Idukki district are depicted in Fig 34, 35, 36 and 37 respectively.

5.6. Land quality index

The land quality index of post-flood soils of AEU ranged from 0.93 kg m^{-2} (Pampadumpara) to 8.78 kg m^{-2}(Rajakumari). The mean value of AEU was found to be 3.85 kg m^{-2}. Anilkumar *et al*. (2015) has also made a similar observation with respect to land quality index of coffee growing tracts of Karnataka where the organic carbon status was low due to high erosion, steep slope and fine soil texture coupled with low bulk density. About 65.8 per cent of soil samples had low land quality index (Fig 38). Spatial distribution of land quality index in the post-flood soils of AEU 16 in Idukki district is depicted in Fig 39.

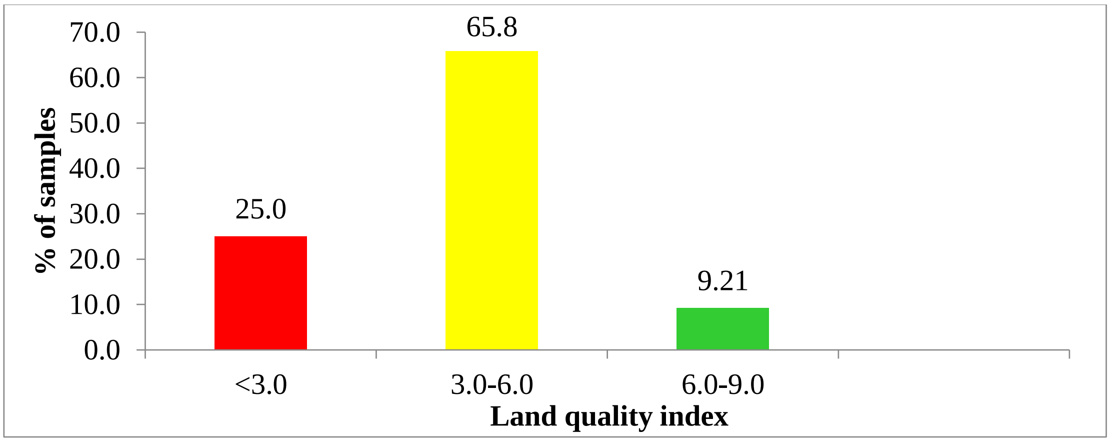

Fig 38. Frequency distribution of land quality index (kg m^{-2}) in the post-flood soils of AEU 16 in Idukki district

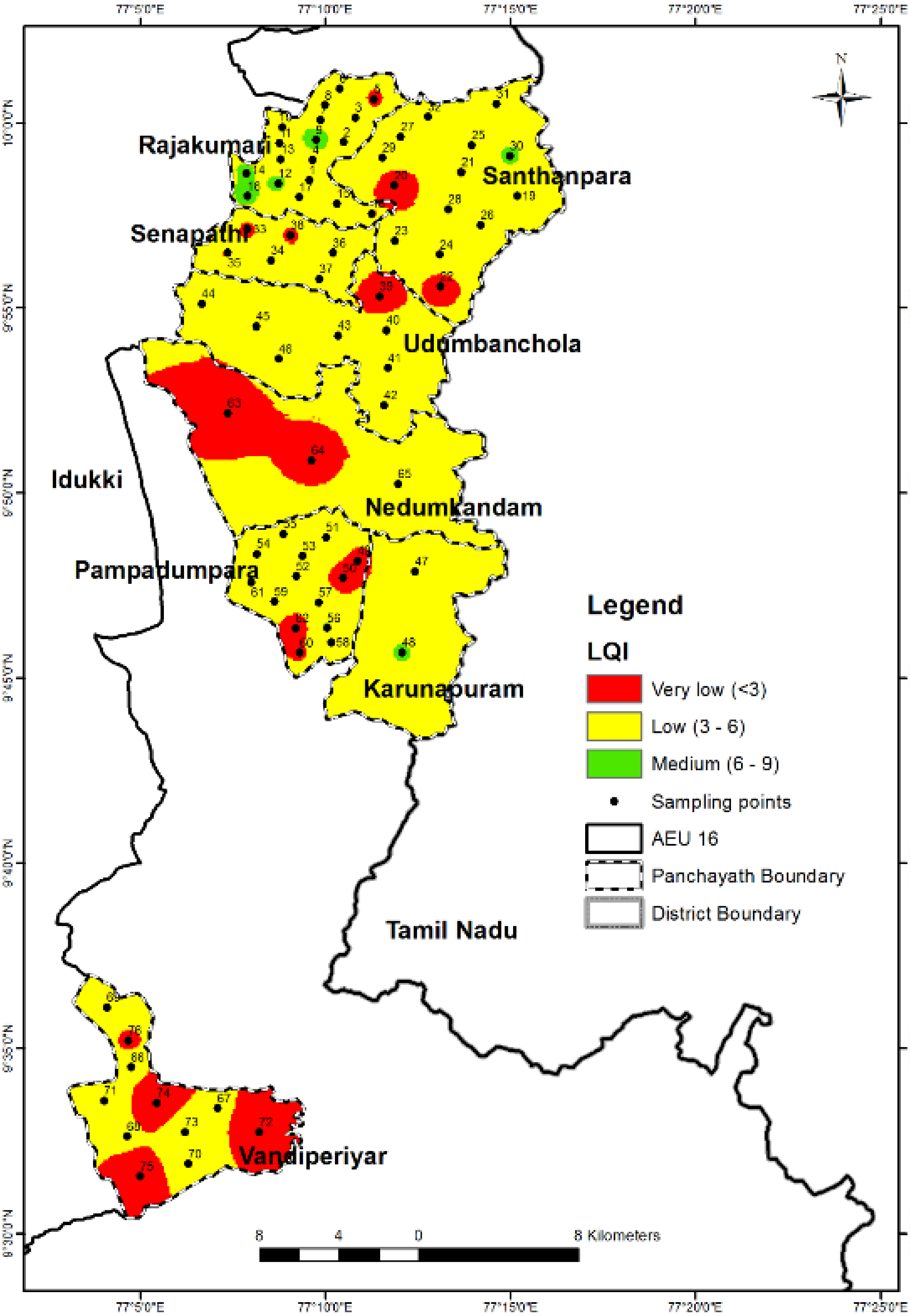

Fig 39. Spatial distribution of land quality index in the post-flood soils of AEU 16 in Idukki district

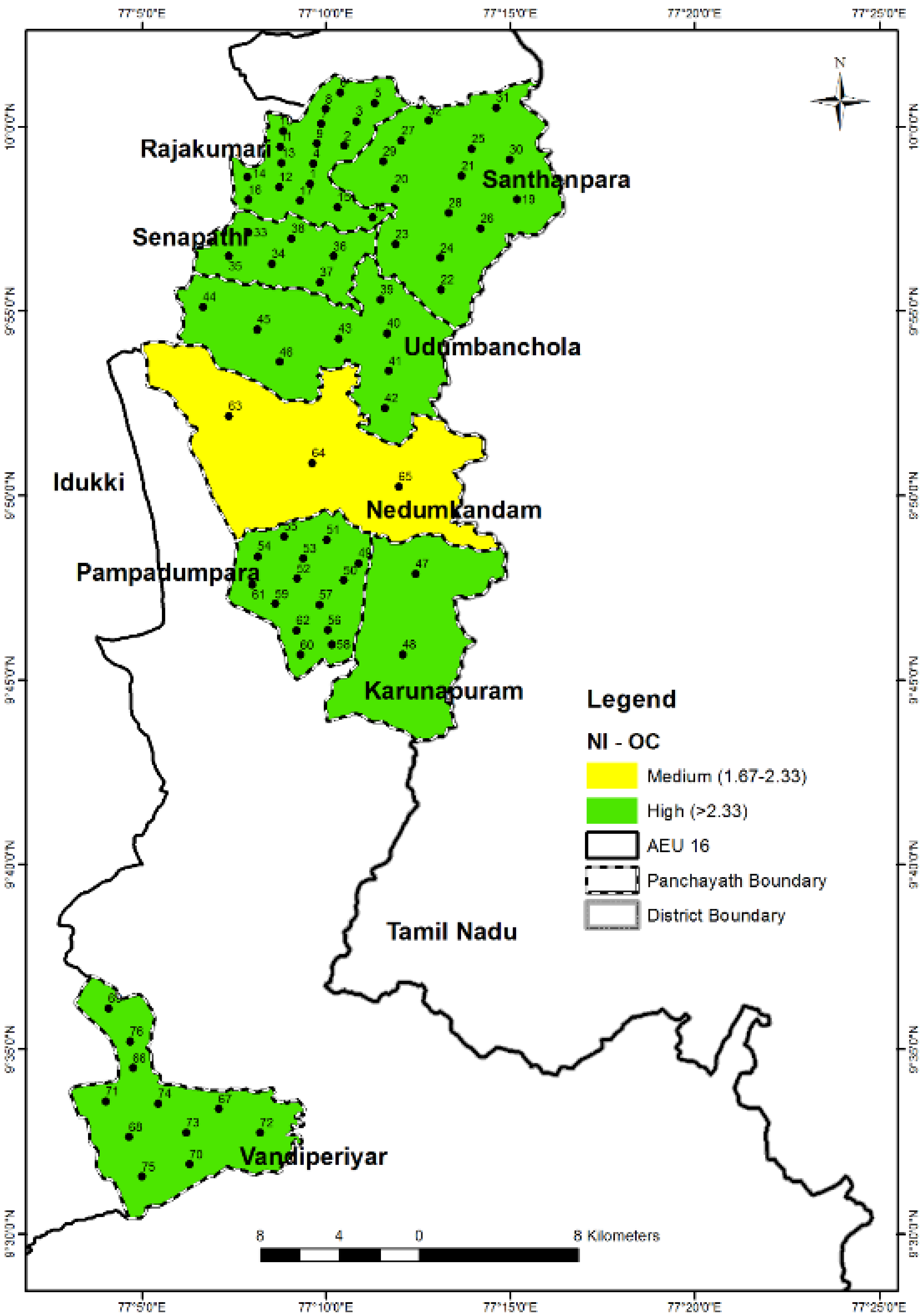

Fig 34. Spatial distribution of nutrient index of organic carbon in the post-flood soils of AEU 16 in Idukki district

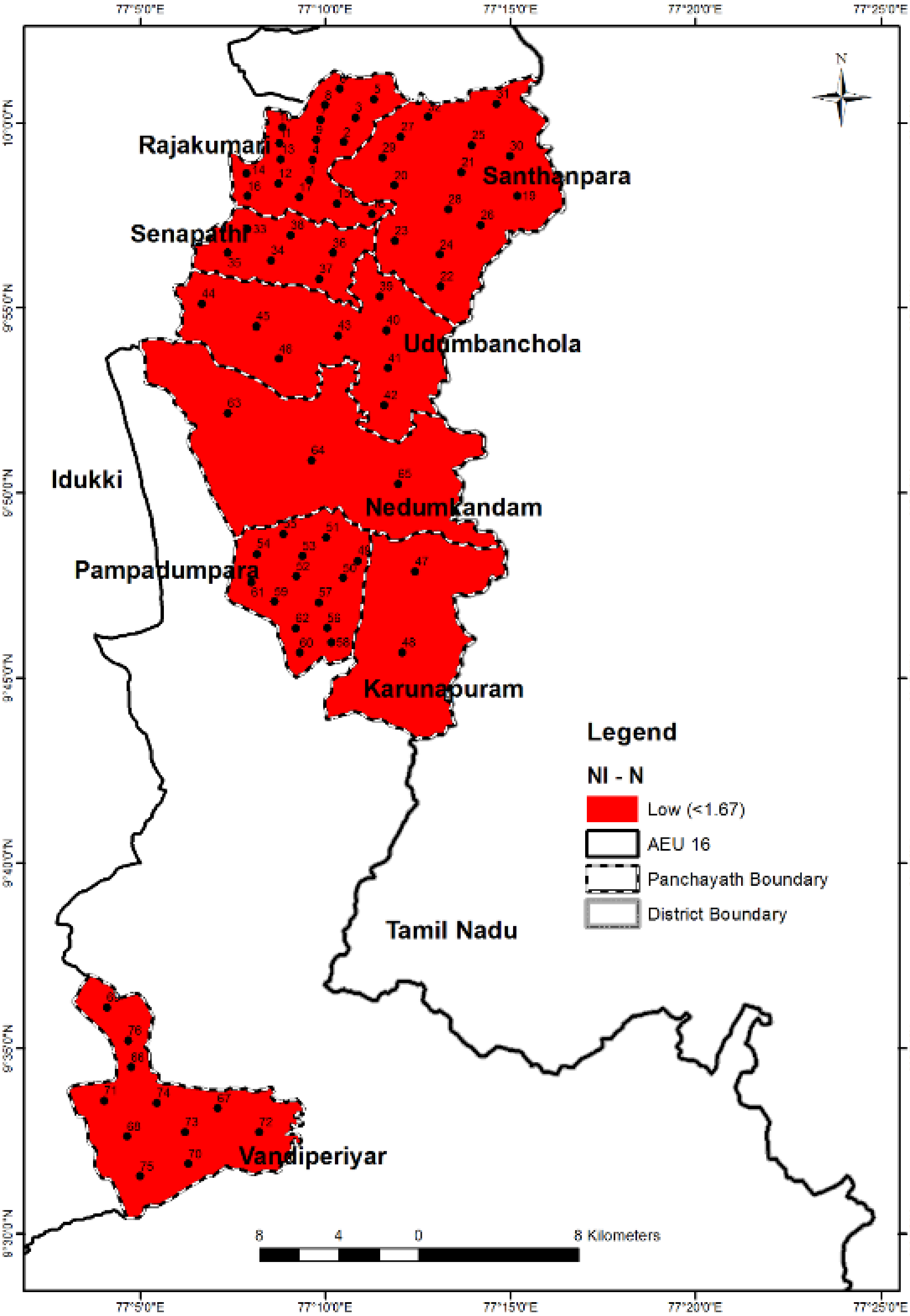

Fig 35. Spatial distribution of nutrient index of available nitrogen in the post-flood soils of AEU 16 in Idukki district

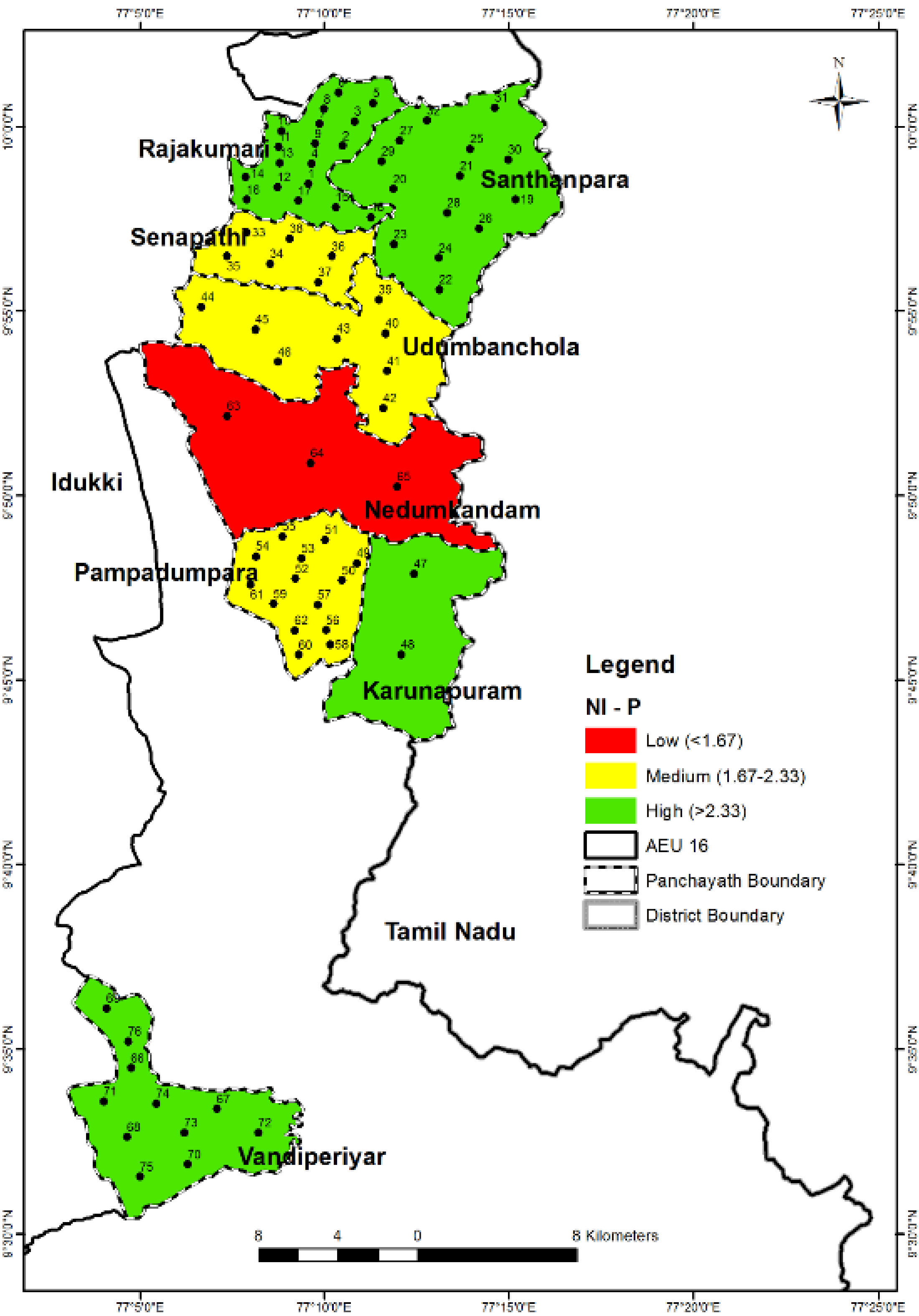

Fig 36. Spatial distribution of nutrient index of available phosphorous in the post-flood soils of AEU 16 in Idukki district

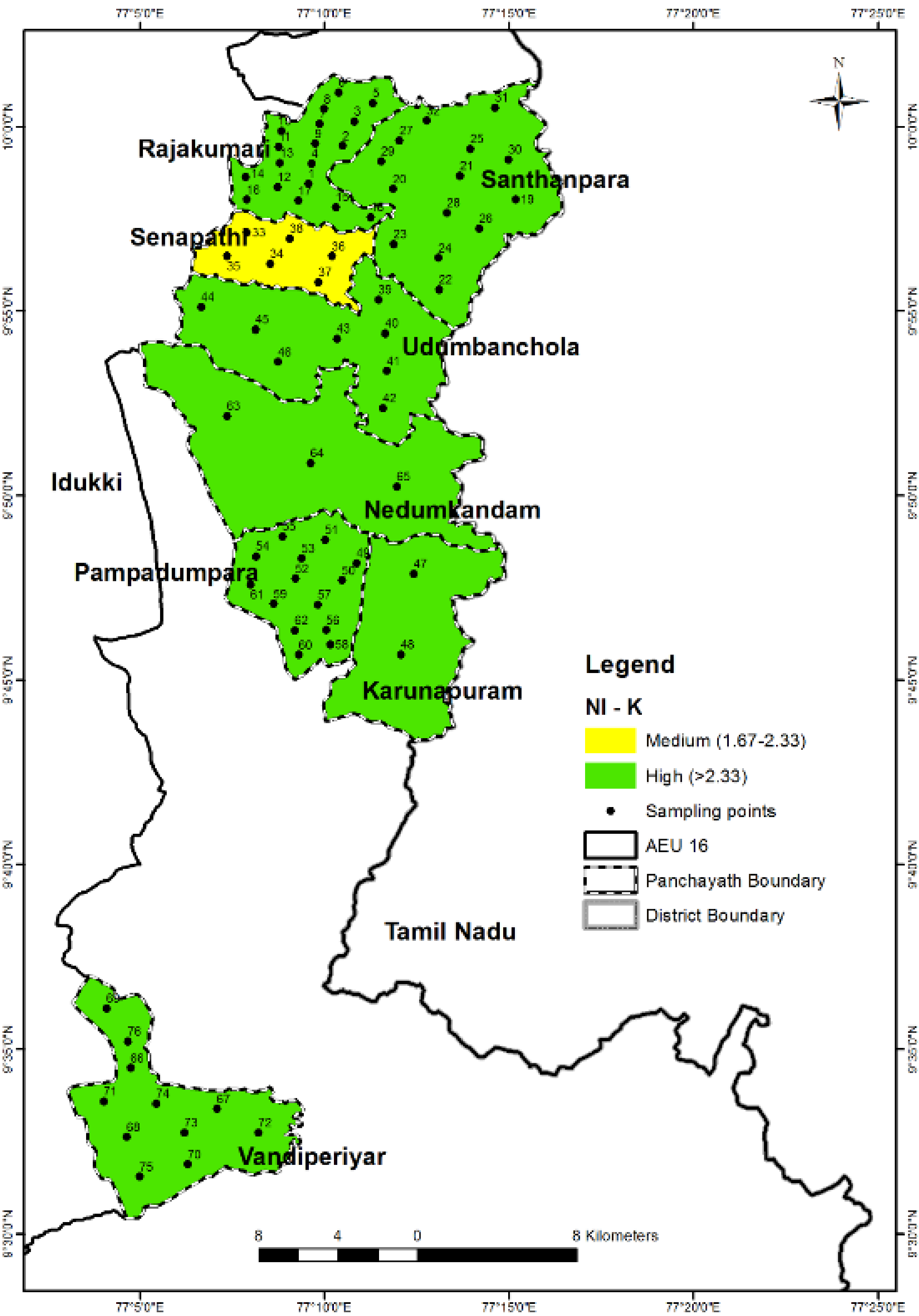

Fig 37. Spatial distribution of nutrient index of available potassium in the post-flood soils of AEU 16 in Idukki district

5.7. Soil fertility class of soils of AEU in the post-flood scenario and crop management strategies

The results of soil analyses categorized based on the 0-9, "ten class system" of classification of soil test results for nutrient management recommendation, (KAU 2016) package of practices are presented in Appendix IV.

Out of the 76 soils analyzed, twelve samples of AEU are falling under "very strongly acidic" class of pH. This warrant application of lime only up to 600 kg ha^{-1} of general package of practice recommendation for crops grown in the region having very strongly acidic class of pH. Fourteen samples of AEU are falling under "strongly acidic" class of pH requiring application of lime up to 350 kg ha^{-1} of general package of practice recommendation for crops grown in the region having strongly acidic class of pH. Sixteen samples of AEU are falling under "moderately acidic" class of pH. For this class application of lime at the rate of 250 kg ha^{-1} of general package of practice recommendation for crops grown in the region. Thirty-four samples of AEU are falling under "slightly acidic" class of pH. This warrant application of lime only up to 100 kg ha^{-1} of general package of practice recommendation for crops grown in the region having slightly acidic class of pH.

Four samples of AEU are categorized under class 5 of organic carbon. Such soils are to be managed with application of nitrogen only up to 84 per cent of general package of practice recommendation for each crop grown in the region. Only one sample of AEU is coming under class 6 of organic carbon. In this case only 78 per cent of nitrogen recommended for the crop is to be applied as per package of practice recommendation for each crop grown in the region. Four samples of AEU are falling under class 7 of organic carbon. In these regions application of nitrogen is to be limited to 71 per cent of package of practice recommendation for each crop cultivated. Under class 8 of organic carbon, there are nine samples of AEU. In these regions application of nitrogen shall be limited to 63 per cent of package of practice recommendation for each crop cultivated. Under the highest category of class nine for organic carbon, there are fifty-eight samples of the AEU. For these regions application of nitrogen shall be restricted to 54 per cent of general package of practice recommendation for each crop grown.

There are seven samples of AEU, which can be grouped under the category class 1 of available P. Phosphorous recommendation to each crop in the region shall be enhances to 117 per cent of package of practice recommendation. Similarly, for the crops grown in regions having eight samples categorized under class 2, nutrient management for P shall be enhanced to 106 per cent of the POP recommendation. Six samples from the AEU are categorized under class 3 of available P. The crops grown in these regions, shall be managed with only 94 percentage of P_2O_5 recommendation as per POP. Crops in the regions with five samples categorized under class 4 of available P shall be managed with P_2O_5 to a level only up to 83 per cent of the POP recommendation. Three samples of AEU are categorized under class 5 of available P. This necessitate application of P_2O_5 phosphorous only up to 71 per cent of general package of practice recommendation for each crop grown in these regions. Five samples of AEU are falling under class 6 of available P. This warrant application of phosphorous only up to 60 per cent of general package of practice recommendation for each crop grown in these regions. Four samples of AEU are falling under class 7 of available P. In these regions, crops shall be managed by applying only 48 per cent of P_2O_5 requirement POP. Two samples of AEU categorized under class 8 of available P. Crops in these regions need to be applied with P_2O_5 only up to 37 per cent of POP. Thirty-six samples of AEU are grouped under class 9 of available P. In these regions only 25 percent of P_2O_5 requirement as per POP need to be supplemented.

Only two samples of AEU come under class 0 category of available K. This warrant application of potassium only up to 128 per cent of general package of practice recommendation for each crop grown in the region having class 0. Only one sample of AEU is banded under class 1 of available K. Here application of potassium needs to be scaled up to 117 per cent of POP for each crop. Again, only one sample of AEU is falling under class 2 of available K. This warrant application of potassium only up to 106 per cent of general package of practice recommendation for each crop grown in the region. Three samples of AEU are bracketed under class 3 of available K, wherein the crops need to be supplemented with K only to a level of 94 per cent of POP in the region. Three samples of AEU are categorized under class 4 of available K. In these regions, application of potassium should be restricted to 83 per cent of POP for each crop. Crops of the regions where the soils are (Five samples of AEU) categorized under class 5 of available K are to be managed with a reduced dose of only 71 per cent of POP. Potassium nutrition to crops shall be restricted to 60 per cent of POP for in the region having class 6 (Only one sample fall under this category). Only three samples of AEU are grouped under class 7 of available K, and in these regions, application of potassium shall be limited to 48 per cent of POP for each crop grown. Soils categorized under class 8 with respect to available K (One sample of AEU) are to be managed with only up to 37 per cent of POP for the respective crop grown in the region. Fifty-six samples of AEU coming under class 9 with respect to available K. In these regions the requirement of potassium for each crop is to be limited to 25 per cent of POP for each crop grown in the region having class 9.

Five samples of AEU were found to be deficient in available Ca, so nutrient management recommendation need to be managed as per the recommendation for managing the soil based on pH value. Six samples were found to be deficient in available Mg, so in those areas, dolomite can be substituted for lime. Twenty-three samples were found to be deficient in available S, so 25 kg $ha^{-1}$of sulphur need to be recommended as per the package of practice. Seventy-three samples were found to be deficient in available B, so either 10 kg ha^{-1} or 0.5% solution of borax need to be recommended as per the package of practice.

SUMMARY

6. SUMMARY

The study entitled "Assessment of soil quality in the post-flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps" was undertaken with the objectives to assess the soil quality in the post-flood scenario of AEU 16 in Idukki district, to develop GIS maps on soil quality and characteristics and to evaluate soil quality index. The study was initiated with survey, collection of data and representative soil samples, followed by characterization of soils of flood affected region. Seventy-six representative geo referenced surface soil samples were collected from eight flood affected panchayaths *viz*., Rajakumari, Santhanpara, Senapathy, Udumbanchola, Pampadumpara, Karunapuram, Nedumkandam and Vandiperiyar. The soil samples were characterized for physical (bulk density, particle density, porosity, texture, water holding capacity, depth of sand/ silt/ clay deposition, soil moisture and aggregate analysis), chemical (pH, EC, OC, available macro, secondary and boron) and biological (acid phosphatase) attributes. Soil quality index was worked out using minimum data set. Nutrient indices for organic carbon and available primary nutrients of all panchayaths as well as the land quality index was also worked out.

The data of the soil samples which were characterized for physical, electro-chemical and biological attributes was interpreted and minimum data set (MDS) was developed using principal component analysis (PCA). Eight principal components were extracted from which ten indicators that highly influenced the soil quality with eigen value greater than one was identified, *viz.*, bulk density, clay per cent, silt per cent, soil moisture content, pH, electrical conductivity, organic carbon, available nitrogen, potassium and boron. Each of the indicators was categorised into four classes. Class I is the most suitable for plant growth; Class II is suitable to plant growth but with slight limitations; Class III is with more serious limitation than Class II; and Class IV is with severe limitations for plant growth. Marks of 4, 3, 2, and 1were given to class I, II, III, and IV respectively. (Kundu *et al*., 2012; Mukherjee and Lal, 2014) with slight modifications. The weight for each indicator was assigned on the basis of existing soil conditions, cropping pattern, and agro-climatic conditions (Singh *et al*., 2017). Soil quality index (SQI) for each sampling site was generated by aggregating the scores following standard methods (Kundu *et al*., 2012). Correlation between the analyzed parameters were worked out. The salient findings of the study are summariszed below.

1. Cardamom, pepper, nutmeg, clove, ginger, paddy, cocoa, banana, cassava, vegetables etc. were the major crops grown. Spices contribute more to the land use of the AEU where 59.2 per cent and 46.1 per cent of farmers cultivate cardamom and pepper respectively. About 65.8 per cent farmers owned a holding size of less than 2 ha.
2. About 59.2 per cent, 21.1 per cent and 19.7 per cent of farmers followed INM, conventional and organic farming respectively.
3. Organic nutrient sources like fresh and dried cow dung, goat manure, vermi compost were preferred by most of the farmers. Dolomite was used more frequently by most of the farmers for the purpose of liming. Urea, rajphos, diammonium phosphate, muriate of potash and complex fertilizer like 18:18 and spraying of 19:19:19 as foliar spray in cardamom growing tracts were most commonly used by farmers.
4. Deposition of sand, silt and clay were observed paddy grown tracts. Deposition of sediments with varying depth and texture was found in Rajakumari, Udumbanchola, Karunapuram and Vandiperiyar panchayaths, of which the sand deposition in Rajakumari panchayath was prominent.
5. Five textural classes were found in the post-flood soils of AEU *viz*., sandy loam, sandy clay loam, sandy clay, clay loam and clay. Sandy loam, sandy clay loam, sandy clay, clay loam and clay soils were found in 17.1 per cent, 17.1 per cent, 15.8 per cent, 23.7 per cent and 26.3 per cent of soil samples respectively.
6. The highest mean of per cent silt (18.2%), soil moisture content (18.5%), water holding capacity (52.7%) and lowest mean weight diameter (0.72 mm) were observed in Vandiperiyar panchayath.
7. The lowest mean of silt content was observed in Santhanpara panchayath (13.2%).
8. Most of the soils had a bulk density less than 1.2 Mg m^{-3} (80.3%), particle density less than 2.2 Mg m^{-3} (88.2%), porosity between 30 and 50 % (68.4%), water

holding capacity between 30 and 50% (79.0%), water stable aggregates between 50 and 70% (59.2%) and mean weight diameter less than 1 mm (72.4%).

9. The highest mean of bulk density (1.14 Mg m^{-3}) per cent sand (62.1%) and lowest mean of per cent clay (22.9%), particle density (1.92 Mg m^{-3}) porosity (40.4%) were observed in Rajakumari panchayath.
10. The highest mean of particle density (2.13 Mg m^{-3}), porosity (51.0%), per cent clay (41.2%) and lowest mean water stable aggregates (63.2%), per cent sand (43.8%), bulk density (1.02 Mg m^{-3}) were observed in Nedumkandam panchayath.
11. The highest mean of water stable aggregates (78.9 %) and mean weight diameter (1.81 mm) and lowest mean of soil moisture content (8.53 %), water holding capacity (39.4 %), per cent sand (43.8 %) were observed in Karunapuram panchayath.
12. Most of the soils had moderately acidic (30.3 %) to strongly acidic (22.4%) pH, electrical conductivity less than 1 dS m^{-1} (100%), high organic carbon (85.5%), available N (77.6%), available P (54.0%), available K (80.3%), available sufficient Ca (93.4%), available Mg (92.1%), available S (72.4%), deficient in available B (96.1%) and acid phosphatase activity between 10 µg PNP produced g $soil^{-1}$ h^{-1} and 25 µg PNP produced g $soil^{-1}$ h^{-1} (42.1%).
13. The highest mean of pH was observed in Nedumkandam and Pampadumpara panchayath (6.16) and the lowest mean in Vandiperiyar panchayath (5.21).
14. The highest mean of electrical conductivity was observed in Santhanpara panchayath (0.18 dS m^{-1}) and the lowest mean in Senapathi and Pampadumpara panchayaths (0.12 dS m^{-1}).
15. The highest mean of organic carbon (3.22%), available N (282 kg ha^{-1}), available P (58.2 kg ha^{-1}), available K (1086 kg ha^{-1}) and lowest mean of available B (0.03 mg kg^{-1}), available Mg (156 mg kg^{-1}) were observed in Karunapuram panchayath
16. The highest mean of available Ca (1060 mg kg^{-1}), available Mg (280 mg kg^{-1}) and lowest mean of available P (6.76 kg ha^{-1}), organic carbon (1.43%) were observed in Nedumkandam panchayath.

17. The lowest mean value of available N (208 kg ha^{-1}), available Ca (540 mg kg^{-1}) and acid phosphatase activity (18.9µg PNP produced g $soil^{-1}$ h^{-1}) were observed in Vandiperiyar panchayath.
18. The lowest mean value of available K (312 kg ha^{-1}) and highest mean of acid phosphatase activity were observed in Senapathi panchayath (54.7 µg PNP produced g $soil^{-1}$ h^{-1}).
19. The lowest mean value of available S was observed in Udumbanchola panchayath (5.00 mg kg^{-1}) and highest mean of available S (21.6 mg kg^{-1}) and available B were observed in Rajakumari panchayath (0.18 mg kg^{-1}).
20. A Minimum Data Set (MDS) was developed using Principal Component Analysis (PCA). Eight principal components were extracted from which ten indicators that highly influenced the soil quality (eigen value >1) were identified, *viz.*, bulk density, clay per cent, silt per cent, soil moisture content, pH, electrical conductivity, organic carbon, available nitrogen, potassium and boron.
21. Soil quality index (SQI) for each sampling site was generated by aggregating the scores following standard methods (Kundu *et al*., 2012).
22. The SQI of AEU ranged from 165 (Vandiperiyar) to 295 (Rajakumari). The mean of SQI in post-flood soils of AEU is 236. The lowest mean of SQI was found in Santhanpara panchayath (221) and highest in Pampadumpara panchayath (244).
23. The relative soil quality index of AEU ranged from 41.3 (Vandiperiyar) to 73.8% (Pampadumpara). The mean value of RSQI of AEU is 59.1%. The lowest mean of RSQI was found in Senapathi panchayath (55.2%) and highest in Pampadumpara panchayath (60.9%).
24. Nutrient index for organic carbon was high for all the panchayaths except for Nedumkandam panchayath which has medium nutrient index. Nutrient index for available N was low in all panchayaths. Nutrient index for available P was high in Karunapuram, Rajakumari, Santhanpara and Vandiperiyar panchayaths, medium in Udumbanchola and Pampadumpara panchayaths and low in Nedumkandam panchayath. Nutrient index for available K was high in all panchayaths except in Senapathi panchayath (medium).

25. Land quality was low for 65.8 per cent of samples. The mean value of AEU was found to be 3.85 kg m^{-2}. The lowest mean value was found in Nedumkandam panchayath (2.21 kg m^{-2}) and highest in Karunapuram panchayath (5.07 kg m^{-2}).
26. In comparison with the pre-flood data of GOK (2013), there is an increase in pH from strongly acidic to moderately acidic, warranting lower requirement of lime.
27. The previous values of organic carbon (68.8%), available P (46.4%) and available K (61.9%) were also high similar to the post-flood status, indicating that there is no shift in the status of these nutrients.
28. Per cent of samples with adequate levels of available Ca (87.8%) and deficient levels of available B (66.6%) were similar in the pre-flood and post-flood study whereas per cent of samples with adequate available Mg and S increased.

a. Thus, the study has shown that the soil fertility of the AEU has been altered in the post-flooded situation. Since there is an increase in soil pH after flood, the requirement of lime was lower. There is a need for application of borax as boron deficiency was found to be very high in the soil. Soil quality as well as nutrient index was found to be high in Vandiperiyar panchayath. There is an improvement of major nutritional factor *viz*., organic carbon, available P and available K requiring lesser quantity of nutrients for satisfying the crop requirement in the AEU 16.

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ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 16 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

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ABSTRACT

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ABSTRACT

The present study entitled “Assessment of soil quality in the post- flood scenario of AEU 16 in Idukki district of Kerala and generation of GIS maps” was conducted during 2018-2020 with the objective of assessing the soil quality of post-flood soils of AEU 16, formulation of Soil Quality Index (SQI) and generation of GIS maps of soil characters and land quality.

The study was initiated with the survey, collection followed by characterization of soil. Seventy-six representative geo referenced surface soil samples were collected from eight flood affected panchayaths *viz*., Rajakumari, Santhanpara, Senapathy, Udumbanchola, Pampadumpara, Karunapuram, Nedumkandam and Vandiperiyar. Cardamom, pepper, nutmeg, clove, ginger, paddy, cocoa, banana, cassava, vegetables etc. were the major crops grown. Farmers commonly use dolomite and organic nutrient sources like fresh and dried cow dung, goat manure, vermi compost etc.

The soil samples were characterized for physical, chemical and biological attributes. The data was interpreted and Minimum Data Set (MDS) was developed using Principal Component Analysis (PCA). Eight principal components were extracted from which ten indicators that highly influenced the soil quality (eigen value >1) were identified, *viz.,* bulk density, clay per cent, silt per cent, soil moisture content, pH, electrical conductivity, organic carbon, available N, K and B. SQI for each sampling site was generated by aggregating the scores following standard methods (Kundu *et al*., 2012). The relative soil quality index of the soils was also calculated and 77.6 per cent of soil samples had medium soil quality index. Correlation between the analysed parameters were worked out.

Deposition of sediments with varying depth and texture was found in Rajakumari, Udumbanchola, Karunapuram and Vandiperiyar panchayaths, of which the sand deposition in Rajakumari panchayath was prominent. Most of the soils had a BD <1.2 Mg m^{-3} (80.3%), PD <2.2 Mg m^{-3} (88.2%), porosity between 30 and 50 % (68.4%), soil moisture content less than 10% (29.0%), WHC between 30 and 50% (79.0%), WSA between 50 and 70% (59.2%) and MWD < 1 mm (72.4%). Soil pH was found to be moderately acidic for 30.3 per cent of the soil samples. All the soil samples had low electrical conductivity in a range less than 1.0 dS m^{-1}. Organic carbon was high

for 85.5 per cent of samples. Available N was low for 77.6 per cent of samples. Available P and available K was high for 54.0 and 80.3 per cent of the samples respectively. Available Ca, Mg and available S were sufficient whereas available B was deficient for most of the samples. Acid phosphatase activity was between 10 and 25 µg PNP produced g soil^{-1} h^{-1} for 42.1 per cent of samples.

The mean of relative soil quality index was found to be highest in Pampadumpara panchayath (60.9% - medium) and lowest in Senapathy panchayath (55.2% - low). Nutrient index for organic carbon was high for all the panchayaths except for Nedumkandam panchayath (medium). Nutrient index for available N was low in all panchayaths. Nutrient index for available P was high in Karunapuram, Rajakumari, Santhanpara and Vandiperiyar panchayaths, medium in Udumbanchola and Pampadumpara panchayaths and low in Nedumkandam panchayath. Nutrient index for available K was high in all panchayaths except in Senapathi panchayath (medium). Land quality was low for 65.8 per cent of samples.

In comparison with the pre-flood data of GOK (2013), there is an increase in pH from strongly acidic to moderately acidic, warranting lower requirement of lime. The previous values of organic carbon, available P and available K were also high similar to the post-flood status, indicating that there is no shift in the status of these nutrients. Per cent of samples with adequate levels of available Ca and available B were similar in the pre-flood and post-flood study whereas per cent of samples with adequate available Mg and available S increased.

Establishment of soil quality index is very important as far as soil health is concerned. It is advisable to analyse the physcio chemical characteristics of soil and derive soil quality index every year, in order to have an effective alternate site-specific management of crops especially in the events of natural calamities. Thus, the present study shows a need for the revision of soil management practices, as there is an improvement of major nutritional factor *viz.*, organic carbon, available P and K requiring only lesser nutrient requirement for maintaining the crops with same level of productivity compared to pre-flooded condition in the AEU 16.

APPENDICES

APPENDIX I

DETAILS OF THE SURVEY CONDUCTED IN THE FLOOD AFFECTED AREAS OF AEU 16

a. Questionnaire of the survey

Name of the panchayath :

Name of the farmer :

Address :

Size of holding :

Survey No. :

Geocoordinates of the sample :

Crops cultivated :

Nutrient management practices :

Depth of sand/ silt/ clay deposition :

b. Details of the Survey

Sl. No.	Size of holding (ha)	Crops	Organic/ INM/ Coventional
1	2.00	Cardamom, Ginger, Pepper	INM
2	1.00	Cardamom, Nutmeg, Pepper	Organic
3	1.50	Cardamom, Pepper, Nutmeg	INM
4	1.00	Cardamom, Pepper	INM
5	0.50	Cardamom, Banana, Pepper	Organic
6	1.00	Cardamom, Nutmeg	INM
7	1.00	Cardamom, Banana	INM
8	1.50	Cardamom, Pepper, Clove	INM
9	1.00	Cardamom, Banana, Pepper	INM
10	1.50	Cardamom, Clove, Pepper	INM
11	2.50	Cardamom, Pepper, Nutmeg, Banana, Clove	INM
12	0.32	Paddy	INM
13	2.00	Pepper, Nutmeg, Banana, Clove	INM
14	2.00	Cardamom, Nutmeg, Banana	INM
15	0.40	Paddy	Conventional
16	2.00	Pepper, Nutmeg, Banana	INM
17	2.50	Cardamom, Nutmeg, Clove, Pepper	INM
18	1.50	Cassava, Nutmeg, Banana, Clove	INM
19	2.50	Pepper, Clove, Nutmeg	INM
20	0.50	Paddy	Conventional
21	0.32	Paddy	Organic
22	0.50	Paddy, Chilli	Organic
23	0.32	Paddy	Conventional
24	0.80	Paddy	INM
25	2.00	Pepper, Nutmeg, Clove	INM
26	0.50	Paddy	Conventional
27	1.00	Pepper, Nutmeg	Organic
28	0.50	Paddy	Conventional
29	0.50	Paddy	Conventional
30	2.00	Cardamom, Clove, Nutmeg	INM
31	0.32	Paddy	Conventional
32	1.50	Pepper, Banana, Clove	INM
33	0.32	Paddy	Conventional
34	2.50	Cardamom, Pepper, Nutmeg, Clove	INM
35	2.50	Cardamom, Cocoa, Nutmeg, Clove	INM
36	2.00	Cardamom, Cocoa, Clove	INM
37	2.00	Cardamom, Cassava, Banana	INM
38	0.32	Paddy	Conventional
39	0.40	Paddy	Conventional
40	0.50	Paddy, Cassava	Organic
41	0.40	Paddy	Conventional
42	0.50	Paddy, Cassava	Organic
43	2.00	Cardamom, Nutmeg, Clove	INM
44	2.00	Cardamom, Cocoa, Clove	INM

(Appendix I (b) -continued)

Sl. No.	**Size of holding (ha)**	**Crops**	**Organic/ INM/ Coventional**
45	0.50	Paddy, Cassava	Organic
46	2.50	Cardamom, Pepper, Clove	INM
47	2.00	Cardamom, Pepper, Cocoa	INM
48	1.50	Cardamom, Nutmeg	INM
49	1.00	Cardamom, Banana, Cocoa	Organic
50	2.00	Cardamom, Pepper	INM
51	1.50	Cardamom, Pepper	INM
52	1.00	Cardamom, Banana	Organic
53	2.50	Cardamom, Banana, Pepper	INM
54	2.00	Cardamom, Pepper	INM
55	2.00	Cardamom, Pepper	INM
56	1.00	Cardamom, Pepper	Conventional
57	2.50	Cardamom, Pepper	INM
58	1.50	Cardamom, Nutmeg	INM
59	1.00	Cardamom, Pepper	INM
60	1.00	Cardamom, Cassava	INM
61	1.50	Cardamom, Pepper	INM
62	2.50	Cardamom, Rubber, Nutmeg	INM
63	1.00	Cardamom, Pepper, Cassava	Conventional
64	1.50	Cardamom, Pepper	INM
65	2.50	Pepper, Nutmeg, Clove, Cassava	INM
66	1.50	Cardamom, Pepper, Banana Cassava	INM
67	0.50	Arecanut, Cassava	Organic
68	2.00	Cardamom, Pepper, Cassava	INM
69	0.80	Cardamom, Clove	Conventional
70	2.00	Cardamom, Pepper, Cassava	INM
71	0.80	Cardamom, Cassava	Conventional
72	1.00	Pepper, Clove, Cassava	Organic
73	1.00	Cardamom, Clove	Conventional
74	0.32	Paddy	Conventional
75	0.80	Banana, Cassava	Organic
76	0.50	Paddy	Conventional

APPENDIX II

SOIL ANALYSIS DATA OF POST-FLOOD SOILS OF AEU 16

a. Physical attributes of post-flood soils of AEU 16

Sample No.	Panchayath	Textural class	Sand %	Silt %	Clay %	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity	Moisture %	WHC	MWD	WSA
1	Rajakumari	sandy loam	73.8	10.0	16.2	1.19	1.94	38.6	15.5	44.1	0.97	74.6
2	Rajakumari	sandy loam	73.8	10.0	16.2	1.29	2.13	39.4	10.4	39.5	1.00	72.8
3	Rajakumari	sandy clay loam	53.8	15.0	31.2	0.99	1.75	43.4	15.8	51.1	0.57	59.8
4	Rajakumari	sandy loam	68.8	15.0	16.2	1.29	1.87	30.9	8.85	39.7	1.38	74.6
5	Rajakumari	sandy clay loam	58.8	10.0	31.2	0.98	1.91	48.6	3.10	49.8	0.51	63.4
6	Rajakumari	sandy clay loam	53.8	15.0	31.2	0.92	1.92	52.0	15.3	44.1	0.87	68.4
7	Rajakumari	sandy loam	68.8	15.0	16.2	1.19	2.03	41.3	30.2	42.1	1.36	77.2
8	Rajakumari	sandy clay loam	58.8	10.0	31.2	0.77	1.94	60.3	50.6	43.8	0.93	65.8
9	Rajakumari	sandy loam	63.8	20.0	16.2	1.25	2.02	38.1	8.23	43.0	1.45	76.0
10	Rajakumari	sandy loam	73.8	10.0	16.2	1.25	1.85	32.4	9.70	41.4	1.25	65.0
11	Rajakumari	sandy loam	63.8	20.0	16.2	1.19	1.87	36.3	28.6	43.2	2.22	77.4
12	Rajakumari	sandy clay loam	48.8	20.0	31.2	1.03	1.81	43.0	23.3	51.4	0.82	73.1
13	Rajakumari	sandy clay loam	48.8	20.0	31.2	1.29	1.93	33.1	12.0	40.6	0.61	67.0
14	Rajakumari	sandy loam	68.8	15.0	16.2	1.29	1.99	35.1	8.85	39.7	1.79	92.4
15	Rajakumari	sandy loam	73.8	.010	16.2	1.13	1.83	38.2	7.05	42.8	1.26	74.4
16	Rajakumari	sandy loam	63.8	20.0	16.2	1.25	2.05	35.1	15.6	45.1	0.88	65.7
17	Rajakumari	sandy clay loam	48.8	20.0	31.2	0.99	1.74	43.0	6.92	54.2	1.09	79.2
18	Rajakumari	sandy clay loam	53.8	15.0	31.2	1.20	1.95	38.4	3.68	39.7	0.56	69.8
19	Santhanpara	sandy clay loam	68.8	10.0	21.2	1.29	1.87	30.9	12.0	42.7	0.66	59.0
20	Santhanpara	sandy loam	68.8	15.0	16.2	1.19	2.01	40.7	28.6	41.3	1.02	70.8
21	Santhanpara	Clay	43.8	10.0	46.2	0.89	2.05	56.5	12.2	56.2	0.61	55.5
22	Santhanpara	sandy loam	63.8	20.0	16.2	1.29	2.38	45.8	9.61	33.1	0.92	54.0
23	Santhanpara	Clay	43.8	15.0	41.2	0.90	1.92	53.1	13.9	47.5	2.05	71.3
24	Santhanpara	sandy clay	53.8	10.0	36.2	0.97	1.96	50.5	12.6	45.7	0.95	60.0

(Appendix II (a)- continued)

Sample No.	Panchayath	Textural class	Sand %	Silt %	Clay %	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity	Moisture %	WHC	MWD	WSA
25	Santhanpara	sandy clay loam	58.8	10.0	31.2	1.18	2.06	42.7	5.48	32.0	0.64	58.8
26	Santhanpara	sandy clay	48.8	15.0	36.2	1.10	2.01	45.2	12.0	43.1	0.76	70.8
27	Santhanpara	sandy clay loam	53.8	15.0	31.2	1.21	1.79	32.3	15.6	36.6	0.67	66.6
28	Santhanpara	Clay	43.8	10.0	46.2	1.13	1.99	43.2	20.7	39.0	0.60	67.8
29	Santhanpara	sandy loam	68.8	15.0	16.2	1.22	1.97	38.0	25.9	40.1	0.92	54.0
30	Santhanpara	Clay	43.8	15.0	41.2	1.11	1.74	36.1	5.91	40.9	0.97	70.4
31	Santhanpara	sandy clay loam	58.8	10.0	31.2	1.18	1.93	38.8	5.48	30.1	0.64	58.8
32	Santhanpara	Clay	43.8	15.0	41.2	1.11	2.04	45.5	39.1	56.7	0.92	69.4
33	Senapathi	sandy clay	53.8	10.0	36.2	1.19	2.30	42.6	17.9	49.5	0.76	67.2
34	Senapathi	Clay	43.8	10.0	46.2	1.05	1.85	43.2	13.9	42.0	0.96	69.0
35	Senapathi	sandy clay	48.8	15.0	36.2	1.07	1.95	45.1	28.3	48.7	0.99	70.5
36	Senapathi	Clay	43.8	15.0	41.2	0.88	2.00	56.0	10.7	55.6	0.84	68.8
37	Senapathi	Clay	43.8	10.0	46.2	1.02	1.98	48.4	6.07	39.7	0.92	69.4
38	Senapathi	Clay	43.8	15.0	41.2	0.95	1.60	40.6	12.2	53.9	0.76	54.4
39	Udumbanchola	clay loam	43.8	20.0	36.2	1.11	2.48	55.2	4.55	36.9	0.67	53.2
40	Udumbanchola	sandy clay	53.8	10.0	36.2	1.15	2.06	44.1	35.7	36.8	0.63	56.4
41	Udumbanchola	Clay	43.8	10.0	46.2	0.95	1.99	52.2	35.9	48.5	0.96	73.0
42	Udumbanchola	clay loam	43.8	20.0	36.2	0.99	1.67	40.7	9.18	48.3	1.04	74.2
43	Udumbanchola	sandy clay	53.8	10.0	36.2	1.07	1.79	40.2	29.7	39.9	0.63	56.4
44	Udumbanchola	clay loam	43.8	25.0	31.2	1.00	1.92	47.9	8.10	45.6	0.95	71.6
45	Udumbanchola	clay loam	43.8	20.0	36.2	0.99	1.99	50.2	9.36	48.0	1.03	75.6
46	Udumbanchola	clay loam	43.8	20.0	36.2	1.00	1.89	47.0	11.0	45.8	1.04	75.4
47	Karunapuram	clay loam	43.8	25.0	31.2	1.25	1.96	36.2	4.98	30.7	1.96	74.9
48	Karunapuram	Clay	43.8	15.0	41.2	0.95	1.97	51.7	12.1	48.0	1.65	83.0
49	Pampadumpara	sandy clay	48.8	15.0	36.2	1.07	2.15	50.2	29.1	43.6	0.65	66.7
50	Pampadumpara	sandy clay loam	68.8	10.0	21.2	0.98	2.55	61.5	13.2	48.5	0.56	57.6
51	Pampadumpara	clay loam	43.8	25.0	31.2	1.28	1.97	26.8	22.6	47.3	1.03	71.8
52	Pampadumpara	Clay	43.8	10.0	46.2	1.13	2.04	44.6	17.7	44.1	0.96	73.0
53	Pampadumpara	clay loam	43.8	20.0	36.2	1.00	2.04	50.9	9.11	46.1	1.03	71.8
54	Pampadumpara	Clay	43.8	15.0	41.2	0.86	1.91	54.9	14.1	48.5	0.92	66.0

(Appendix II (a)- continued)

Sample No.	Panchayath	Textural class	Sand %	Silt %	Clay %	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity	Moisture %	WHC	MWD	WSA
55	Pampadumpara	sandy clay	53.8	10.0	36.2	1.07	2.06	48.0	28.8	39.0	0.68	63.2
56	Pampadumpara	clay loam	43.8	20.0	36.2	1.20	1.82	20.2	31.1	73.0	1.12	75.4
57	Pampadumpara	Clay	43.8	15.0	41.2	0.97	1.83	46.9	13.6	44.3	2.62	86.4
58	Pampadumpara	Clay	43.8	10.0	46.2	1.15	1.88	38.8	35.7	41.2	0.59	74.0
59	Pampadumpara	Clay	43.8	10.0	46.2	0.99	1.89	47.6	10.9	68.8	1.08	80.4
60	Pampadumpara	clay loam	43.8	20.0	36.2	1.08	1.94	44.3	27.6	46.1	0.77	53.4
61	Pampadumpara	sandy clay	48.8	15.0	36.2	1.03	1.60	35.5	17.0	43.9	0.93	66.8
62	Pampadumpara	clay loam	43.8	25.0	31.2	0.87	2.04	57.3	14.1	55.8	0.77	53.4
63	Nedumkandam	Clay	43.8	15.0	41.2	1.01	2.34	56.8	5.38	51.4	0.92	60.6
64	Nedumkandam	Clay	43.8	10.0	46.2	0.99	2.31	57.1	14.8	50.5	2.34	75.6
65	Nedumkandam	clay loam	43.8	20.0	36.2	1.07	1.76	39.1	27.6	45.6	0.77	53.4
66	Vandiperiyar	Clay	43.8	15.0	41.2	1.00	1.99	49.7	4.30	54.1	0.48	59.8
67	Vandiperiyar	clay loam	43.8	25.0	31.2	0.85	1.65	48.4	13.8	47.4	0.80	67.6
68	Vandiperiyar	sandy clay	53.8	10.0	36.2	1.20	2.02	33.6	19.1	49.6	0.92	65.9
69	Vandiperiyar	clay loam	43.8	20.0	36.2	1.08	1.77	38.9	27.0	46.5	0.80	67.6
70	Vandiperiyar	Clay	43.8	10.0	46.2	0.89	1.99	55.2	14.6	48.2	0.56	69.8
71	Vandiperiyar	clay loam	43.8	25.0	31.2	1.18	2.07	30.4	31.7	73.5	0.83	68.7
72	Vandiperiyar	sandy clay	48.8	15.0	36.2	1.03	2.44	57.8	6.40	45.0	0.30	33.8
73	Vandiperiyar	clay loam	43.8	20.0	36.2	1.21	2.07	29.4	30.0	69.2	0.89	69.1
74	Vandiperiyar	clay loam	43.8	25.0	31.2	0.85	2.68	68.3	17.3	60.9	0.70	66.5
75	Vandiperiyar	sandy clay	48.8	15.0	36.2	1.25	2.06	34.9	14.2	42.4	0.91	66.2
76	Vandiperiyar	clay loam	43.8	20.0	36.2	1.10	2.66	58.6	25.4	43.4	0.71	65.7

b. Chemical and biological attributes of post-flood soils of AEU 16

Sample No.	Panchayath	pH	EC	OC %	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av. Ca (kg ha^{-1})	Av. Mg (kg ha^{-1})	Av. S (mg kg^{-1})	Av. B (mg kg^{-1})	Acid phosphatase (µg PNP produced g soil^{-1} h^{-1})
1	Rajakumari	6.00	0.09	1.74	188	11.9	414	760	216	3.50	0.06	30.8
2	Rajakumari	5.59	0.14	2.37	314	44.2	448	1140	192	4.00	0.07	21.9
3	Rajakumari	5.71	0.20	3.81	289	26.7	1613	980	264	75.0	0.74	30.1
4	Rajakumari	4.80	0.10	1.65	263	140.2	202	640	156	6.00	0.05	29.9
5	Rajakumari	4.92	0.19	1.62	238	3.70	224	360	120	7.00	0.04	17.8
6	Rajakumari	5.22	0.14	3.00	301	36.5	448	460	120	7.00	0.34	22.3
7	Rajakumari	5.96	0.12	2.69	339	20.3	504	580	156	8.00	0.10	34.3
8	Rajakumari	5.56	0.24	4.26	263	60.3	1042	1220	204	60.0	0.39	26.6
9	Rajakumari	5.33	0.14	4.68	339	45.4	818	880	216	6.00	0.06	29.4
10	Rajakumari	4.62	0.43	2.16	276	71.5	470	340	216	31.0	0.07	40.9
11	Rajakumari	6.10	0.11	2.93	213	165	269	1120	180	23.5	0.06	47.3
12	Rajakumari	6.31	0.23	4.41	364	42.6	1098	1480	360	71.5	0.18	58.9
13	Rajakumari	6.11	0.15	2.54	213	50.3	381	820	252	2.50	0.52	19.5
14	Rajakumari	6.30	0.17	3.24	238	120	168	500	780	16.5	0.01	9.82
15	Rajakumari	6.87	0.34	3.05	238	58.6	1064	1480	228	19.0	0.02	61.5
16	Rajakumari	6.32	0.14	3.48	276	9.63	493	1160	276	1.00	0.27	24.3
17	Rajakumari	6.63	0.34	2.04	226	9.30	974	1360	336	35.5	0.18	15.8
18	Rajakumari	5.86	0.22	1.65	238	93.4	280	800	216	11.5	0.05	50.4
19	Santhanpara	6.13	0.08	1.98	201	39.9	627	1200	240	16.5	0.12	16.2
20	Santhanpara	5.01	0.04	0.63	163	9.18	22.4	220	96	1.00	0.09	10.4
21	Santhanpara	5.25	0.24	2.19	313	26.1	101	820	204	1.00	0.02	9.00
22	Santhanpara	4.76	0.18	1.35	238	11.2	56.0	400	192	4.50	0.11	22.6
23	Santhanpara	6.03	0.11	2.70	226	34.1	358	920	288	61.5	0.31	32.3
24	Santhanpara	6.10	0.14	2.78	326	54.0	201.6	1240	312	14.5	0.04	36.0
25	Santhanpara	6.37	0.12	2.30	201	19.5	716.8	1300	216	5.50	0.02	26.6
26	Santhanpara	5.96	0.09	2.30	314	38.6	470.4	980	192	3.50	0.10	30.0
27	Santhanpara	6.03	0.14	2.69	213	14.6	369.6	740	528	6.00	0.10	10.6
28	Santhanpara	6.03	0.07	2.04	213	18.9	840	980	228	32.0	0.28	45.5

(Appendix II (b)- continued)

Sample No.	Panchayath	pH	EC	OC %	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av. Ca (kg ha^{-1})	Av. Mg (kg ha^{-1})	Av. S (mg kg^{-1})	Av. B (mg kg^{-1})	Acid phosphatase (µg PNP produced g soil^{-1} h^{-1})
29	Santhanpara	6.83	0.30	2.42	213	22.7	1520	940	252	11.0	0.16	6.91
30	Santhanpara	6.56	0.52	3.90	339	154	717	1480	288	24.5	0.05	67.4
31	Santhanpara	5.15	0.18	2.67	213	54.5	638	540	204	6.00	0.06	18.9
32	Santhanpara	6.92	0.30	2.82	301	69.8	426	1480	288	7.50	0.09	39.0
33	Senapathi	5.05	0.06	1.34	151	10.9	202	180	252	9.00	0.02	31.9
34	Senapathi	6.50	0.14	2.04	188	11.2	549	1340	288	1.50	0.02	61.9
35	Senapathi	5.19	0.10	1.85	289	16.7	33.6	340	120	5.50	0.04	26.3
36	Senapathi	6.07	0.20	2.99	213	35.8	504	1120	108	6.50	0.03	85.2
37	Senapathi	5.96	0.11	2.12	213	30.4	459	940	216	13.5	0.10	47.8
38	Senapathi	6.07	0.14	1.92	376	5.94	123	880	276	74.5	0.02	75.1
39	Udumbanchola	5.30	0.05	1.20	226	7.95	459	940	192	3.50	0.19	25.1
40	Udumbanchola	5.99	0.07	2.15	251	5.04	291	960	240	1.00	0.02	11.5
41	Udumbanchola	6.02	0.22	2.70	251	136	370	1480	264	2.50	0.04	58.4
42	Udumbanchola	6.47	0.13	2.18	226	15.7	504	1240	144	7.00	0.36	26.2
43	Udumbanchola	5.60	0.15	2.37	213	28.9	1254	660	216	9.00	0.15	22.5
44	Udumbanchola	4.72	0.08	2.16	263	150	459	160	48	2.00	0.08	5.36
45	Udumbanchola	5.99	0.24	2.27	314	35.2	918	900	180	5.00	0.02	29.1
46	Udumbanchola	6.06	0.13	2.60	226	26.0	930	840	288	10.0	0.44	23.5
47	Karunapuram	6.33	0.29	2.12	276	50.4	1725	500	108	4.00	0.04	18.1
48	Karunapuram	5.44	0.19	4.32	289	66.1	448	1220	204	16.5	0.02	44.7
49	Pampadumpara	6.54	0.09	1.53	238	49.3	224	960	228	46.0	0.02	55.5
50	Pampadumpara	5.72	0.10	1.05	251	24.4	358	820	216	9.50	0.06	33.8
51	Pampadumpara	6.06	0.08	2.55	389	9.07	448	880	192	0.50	0.06	12.0
52	Pampadumpara	6.64	0.28	2.76	213	21.7	1366	1140	336	7.10	0.01	65.5
53	Pampadumpara	6.39	0.12	3.10	276	75.9	381	1220	276	9.00	0.08	29.8
54	Pampadumpara	6.61	0.17	2.54	226	12.1	896	960	204	2.50	0.05	24.1
55	Pampadumpara	6.20	0.11	2.50	238	24.0	358	860	180	33.0	0.06	30.6
56	Pampadumpara	5.95	0.11	2.93	251	6.83	1288	760	240	7.00	0.04	22.5
57	Pampadumpara	4.89	0.04	2.88	226	191	1310	560	156	26.5	0.21	33.1
58	Pampadumpara	4.80	0.11	2.78	251	54.5	347	360	108	13.0	0.66	20.5

(Appendix II(b) -continued)

Sample No.	Panchayath	pH	EC	OC %	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av. Ca (kg ha^{-1})	Av. Mg (kg ha^{-1})	Av. S (mg kg^{-1})	Av. B (mg kg^{-1})	Acid phosphatase (µg PNP produced g soil^{-1} h^{-1})
59	Pampadumpara	5.40	0.13	3.05	251	66.3	493	580	156	10.5	0.02	15.3
60	Pampadumpara	5.68	0.09	1.73	163	23.0	728	620	216	3.00	0.04	11.8
61	Pampadumpara	6.58	0.25	2.76	276	98.5	1086	1460	312	21.5	0.22	25.5
62	Pampadumpara	5.85	0.05	0.71	226	5.94	146	1040	240	4.00	0.04	12.9
63	Nedumkandam	6.69	0.21	1.04	263	4.70	291	680	156	1.00	0.02	10.7
64	Nedumkandam	6.16	0.24	1.35	201	2.90	851	1400	288	18.0	0.08	27.8
65	Nedumkandam	5.64	0.06	1.90	326	15.0	381	1100	396	2.50	0.03	27.8
66	Vandiperiyar	4.80	0.16	2.18	226	8.06	493	280	168	30.5	0.15	18.8
67	Vandiperiyar	5.00	0.08	2.43	226	54.9	470	480	156	4.50	0.06	16.4
68	Vandiperiyar	6.06	0.10	1.58	201	12.5	168	760	216	12.5	0.10	18.2
69	Vandiperiyar	4.73	0.11	2.45	188	55.4	381	120	192	21.0	0.23	16.9
70	Vandiperiyar	4.99	0.05	2.75	188	67.9	414	400	144	31.0	0.05	26.0
71	Vandiperiyar	5.15	0.11	2.25	201	46.3	728	700	96	6.00	0.04	14.3
72	Vandiperiyar	5.37	0.13	1.40	201	14.9	179	540	180	2.00	0.10	28.1
73	Vandiperiyar	4.97	0.09	1.98	251	24.0	672	700	168	5.50	0.03	20.5
74	Vandiperiyar	5.94	0.42	0.93	213	9.63	661	920	192	6.00	0.04	18.5
75	Vandiperiyar	5.38	0.30	0.99	176	3.81	370	660	156	52.0	0.06	12.2
76	Vandiperiyar	4.96	0.36	1.74	213	4.14	952	380	132	3.00	0.10	18.3

Av. – Available

c. Soil Quality Index and Land Quality Index of post-flood soils of AEU 16

Sample No.	Panchayath	Soil Organic Carbon Stock (Mg ha^{-1})	Land Quality Index (kg m^{-2})	Soil Quality Index	Relative Soil Quality Index (%)
1	Rajakumari	31.1	3.11	260	70.0
2	Rajakumari	45.9	4.59	255	71.3
3	Rajakumari	56.6	5.66	295	73.8
4	Rajakumari	31.9	3.19	205	61.3
5	Rajakumari	23.8	2.38	185	53.8
6	Rajakumari	41.4	4.14	255	66.3
7	Rajakumari	48.0	4.80	275	72.5
8	Rajakumari	49.2	4.92	250	66.3
9	Rajakumari	87.8	8.78	230	66.3
10	Rajakumari	40.5	4.05	230	66.3
11	Rajakumari	52.3	5.23	230	62.5
12	Rajakumari	68.1	6.81	275	71.3
13	Rajakumari	49.1	4.91	265	73.8
14	Rajakumari	62.7	6.27	215	63.8
15	Rajakumari	51.7	5.17	235	67.5
16	Rajakumari	65.3	6.94	280	76.3
17	Rajakumari	30.3	3.03	225	63.8
18	Rajakumari	29.7	2.97	215	63.8
19	Santhanpara	38.3	3.83	250	71.3
20	Santhanpara	11.2	1.12	190	50.0
21	Santhanpara	29.2	2.92	200	53.8
22	Santhanpara	26.1	2.61	200	58.8
23	Santhanpara	36.5	3.65	235	63.8
24	Santhanpara	40.4	4.04	240	63.8
25	Santhanpara	40.7	4.07	225	65.0
26	Santhanpara	38.0	3.80	235	65.0

(Appendix III (c)- continued)

Sample No.	Panchayath	Soil Organic Carbon Stock (Mg ha^{-1})	Land Quality Index (kg m^{-2})	Soil Quality Index	Relative Soil Quality Index (%)
27	Santhanpara	48.8	4.88	280	76.3
28	Santhanpara	34.6	3.46	260	70.0
29	Santhanpara	44.3	4.43	290	78.8
30	Santhanpara	64.9	6.49	240	67.5
31	Santhanpara	47.3	4.73	205	60.0
32	Santhanpara	47.0	4.70	285	75.0
33	Senapathi	23.9	2.65	230	62.5
34	Senapathi	32.1	3.21	235	63.8
35	Senapathi	29.7	2.97	215	56.3
36	Senapathi	39.5	3.95	220	61.3
37	Senapathi	32.4	3.24	195	56.3
38	Senapathi	27.4	2.74	230	61.3
39	Udumbanchola	20.0	2.00	205	60.0
40	Udumbanchola	37.1	3.71	250	67.5
41	Udumbanchola	38.5	3.85	250	66.3
42	Udumbanchola	32.4	3.24	230	63.8
43	Udumbanchola	38.0	3.80	240	63.8
44	Udumbanchola	32.4	3.24	195	56.3
45	Udumbanchola	33.7	3.37	235	63.8
46	Udumbanchola	39.0	3.90	230	63.8
47	Karunapuram	39.8	3.98	235	68.8
48	Karunapuram	61.6	6.16	230	61.3
49	Pampadumpara	24.6	2.46	250	66.3
50	Pampadumpara	15.4	1.54	235	63.8
51	Pampadumpara	49.0	5.51	295	78.8
52	Pampadumpara	46.8	4.68	270	72.5
53	Pampadumpara	46.5	4.65	230	63.8
54	Pampadumpara	32.8	3.28	245	66.3

(Appendix III (c)- continued)

Sample No.	Panchayath	Soil Organic Carbon Stock (Mg ha^{-1})	Land Quality Index (kg m^{-2})	Soil Quality Index	Relative Soil Quality Index (%)
55	Pampadumpara	40.1	4.01	250	66.3
56	Pampadumpara	52.7	6.37	270	73.8
57	Pampadumpara	41.9	4.19	215	58.8
58	Pampadumpara	48.0	4.80	255	67.5
59	Pampadumpara	45.3	4.53	200	56.3
60	Pampadumpara	28.0	2.80	250	66.3
61	Pampadumpara	42.6	4.26	260	68.8
62	Pampadumpara	9.30	0.93	185	48.8
63	Nedumkandam	15.8	1.58	215	61.3
64	Nedumkandam	20.0	2.00	235	63.8
65	Nedumkandam	30.5	3.05	265	68.8
66	Vandiperiyar	32.7	3.27	185	53.8
67	Vandiperiyar	31.0	3.10	225	61.3
68	Vandiperiyar	28.4	3.18	250	68.8
69	Vandiperiyar	39.7	3.97	240	63.8
70	Vandiperiyar	36.7	3.67	215	58.8
71	Vandiperiyar	39.8	4.86	250	67.5
72	Vandiperiyar	21.6	2.16	165	48.8
73	Vandiperiyar	35.9	4.34	260	71.3
74	Vandiperiyar	11.9	1.19	235	61.3
75	Vandiperiyar	18.6	1.99	220	61.3
76	Vandiperiyar	28.7	2.87	250	67.5

APPENDIX III

PRE- AND POST-FLOOD STATUS OF SOIL REACTION AND NUTRIENTS IN AEU 16

Parameter	Fertility class	Per cent samples	
		Pre-flood status (KSPB, 2013)	Post-flood status
pH	Extremely acidic	6.88	17.1
	Very strongly acidic	29.0	17.1
	Strongly acidic	29.8	22.4
	Moderately acidic	21.8	30.3
	Slightly acidic	11.3	13.2
	Neutral or alkaline	1.50	
Organic carbon (%)	Low	4.75	
	Medium	26.4	14.5
	High	68.8	85.5
Available P (kg ha^{-1})	Low	27.9	22.4
	Medium	25.8	23.7
	High	46.4	53.9
Available K (kg ha^{-1})	Low	13.1	5.26
	Medium	25.0	14.5
	High	61.9	80.3
Available Ca (mg kg^{1})	Deficient	12.3	6.58
	Sufficient	87.8	93.4
Available Mg (mg kg^{1})	Deficient	52.6	7.89
	Sufficient	47.4	92.1
Available S (mg kg^{1})	Deficient	71.4	27.6
	Sufficient	28.6	72.4
Available B (mg kg^{1})	Deficient	66.6	96.1
	Sufficient	33.4	3.95

APPENDIX IV

SOIL FERTILITY CLASS AND NUTRIENT MANAGEMENT RECOMMENDATION AS PER PACKAGE OF PRACTICE KAU (2016)

1. **SOIL FERTILTITY CLASS**

a. **pH**

Panchayath							
Rajakumari	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	3	2	5	8
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	600	350	250	100
Santhanpara	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	1	3	1	9
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	600	350	250	100
Senapathi	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	-	2	1	3
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	-	350	250	100

(Appendix IV 1(a)- continued)

Panchayath							
Udumbanchola	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	1	1	3	3
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	600	350	250	100
Karunapuram	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	-	1	-	1
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	-	350	-	100
Pampadumpara	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	2	1	4	7
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	600	350	250	100
Nedumkandam	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	-	-	1	2
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	-	-	250	100
Vandiperiyar	Class	Ultra acid	Extremely acid	Very Strongly acid	Strongly acid	Moderately acid	Slightly acid
	No. of samples	-	-	5	4	1	1
	Lime requirement based on POP (kg $CaCO_3$ ha^{-1})	-	-	600	350	250	100

b. Organic carbon, Available P and K

Organic carbon											
Panchayath											
Rajakumari	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	-	-	18
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	-	-	-	-	54
Santhanpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	1	-	-	1	12
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	84	-	-	63	54
Senapathi	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	-	3	3
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	-	-	-	63	54
Udumbanchola	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	1	-	-	2	5
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	84	-	-	63	54
Karunapuram	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	-	1	1
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	-	-	-	63	54
Pampadumpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	2	-	12
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	-	-	71	-	54

(Appendix IV 1(b)- continued)

Panchayath											
Nedumkandam	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	1	1	-	1	-
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	84	78	-	63	-
Vandiperiyar	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	1	-	2	1	7
	Nitrogen as % of general recommendation (kg ha^{-1})	-	-	-	-	-	84	-	71	63	54
Available P (kg ha^{-1})											
Panchayath											
Rajakumari	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	1	1	1	-	1	-	1	-	13
	Phosphorous as % of general recommendation (kg ha^{-1})	-	117	106	94	-	71	-	48	-	25
Santhanpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	1	1	1	2	1	1	-	7
	Phosphorous as % of general recommendation (kg ha^{-1})	-	-	106	94	83	71	60	48	-	25
Senapathi	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	1	-	2	1	-	-	-	1	1
	Phosphorous as % of general recommendation (kg ha^{-1})	-	117	-	94	83	-	-	-	37	25

(Appendix IV 1(b)- continued)

Panchayath											
Udumbanchola	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	1	1	-	1	-	-	1	1	3
	Phosphorous as % of general recommendation (kg ha^{-1})	-	117	106	-	83	-	-	48	37	25
Karunapuram	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	-	-	2
	Phosphorous as % of general recommendation (kg ha^{-1})	-	-	-	-	-	-	-	-	-	25
Pampadumpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	1	2	1	-	-	3	1	-	6
	Phosphorous as % of general recommendation (kg ha^{-1})	-	117	106	94	-	-	60	48	-	25
Nedumkandam	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	1	1	-	-	1	-	-	-	-	-
	Phosphorous as % of general recommendation (kg ha^{-1})	128	117	-	-	83	-	-	-	-	-
Vandiperiyar	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	2	2	1	1	-	1	-	-	4
	Phosphorous as % of general recommendation (kg ha^{-1})	-	117	106	94	83	-	60	-	-	25

Available K ($kg\ ha^{-1}$)											
Panchayath											
Rajakumari	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	1	2	1	1	-	13
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	-	-	-	-	83	71	60	48	-	25
Santhanpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	1	1	1	-	-	1	-	-	-	10
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	128	117	106	-	-	71	-	-	-	25
Senapathi	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	1	-	-	1	-	1	-	-	-	3
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	128	-	-	94	-	71	-	-	-	25
Udumbanchola	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	1	-	7
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	-	-	-	-	-	-	-	48	-	25
Karunapuram	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	-	-	-	-	-	2
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	-	-	-	-	-	-	-	-	-	25
Pampadumpara	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	1	-	1	-	-	1	11
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	-	-	-	94	-	71	-	-	37	25
Nedumkandam	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	1	-	-	-	1	-	1
	Potassium as % of general recommendation ($kg\ ha^{-1}$)	-	-	-	94	-	-	-	48	-	25

(Appendix IV 1(b)- continued)

Panchayath											
Vandiperiyar	Class	0	1	2	3	4	5	6	7	8	9
	No. of samples	-	-	-	-	2	-	-	-	-	9
	Potassium as % of general recommendation (kg ha^{-1})	-	-	-	-	83	-	-	-	-	25

2. NUTRIENT MANAGEMENT OF MAJOR CROPS OF AEU IN THE POST-FLOOD SCENARIO

Sample No.	Crops	N (g $plant^{-1}$)	P (g $plant^{-1}$)	K (g $plant^{-1}$)	Liming material (kg ha^{-1})	
					Lime	Dolomite
1	Cardamom	65.2	141	100	100	
	Ginger	0.65	1.00	0.33		
	Pepper	109	250	250		
2	Cardamom	65.2	150	100	250	
	Nutmeg	1087	1250	1667		
	Pepper	109	250	250		
3	Cardamom	65.2	72	100	250	
	Pepper	109	250	250		
	Nutmeg	1087	1250	1667		
4	Cardamom	65.2	150	71	600	
	Pepper	109	250	250		
5	Cardamom	65.2	176	71	600	
	Banana	413	575	500		
	Pepper	109	250	250		
6	Cardamom	65.2	150	100	350	
	Nutmeg	1087	1250	1667		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
7	Cardamom	65.2	107	100	250	
	Banana	413	575	500		
8	Cardamom	65.2	150	100	250	
	Pepper	109	250	250		
	Clove	652	1250	1250		
9	Cardamom	65.2	150	100	350	
	Banana	413	575	500		
	Pepper	109	250	250		
10	Cardamom	65.2	150	100	600	
	Clove	652	1250	1250		
	Pepper	109	250	250		
11	Cardamom	65.2	150	60.0	100	
	Pepper	109	250	250		
	Nutmeg	1087	1250	1667		
	Banana	413	575	500		
	Clove	652	1250	1250		
12	Paddy	0.26	0.30	0.10	100	
13	Pepper	109	250	62.5	100	
	Nutmeg	1087	1250	1383		
	Banana	413	575	500		
	Clove	652	1250	1250		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
14	Cardamom	65.2	150	100	100	
	Nutmeg	1087	1250	1667		
	Banana	413	575	500		
15	Paddy	0.26	0.30	0.10		
16	Pepper	109	265	250	100	
	Nutmeg	1087	1250	1667		
	Banana	413	575	500		
17	Cardamom	65.2	159	100		
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		
	Pepper	109	250	250		
18	Cassava	6.11	14.1	2.25	250	
	Nutmeg	1087	1250	1667		
	Banana	413	575	500		
	Clove	652	1250	1250		
19	Pepper	109	250	250	100	
	Clove	652	1250	1250		
	Nutmeg	1087	1250	1667		
20	Paddy	0.22	0.32	0.13		321
21	Paddy	0.14	0.14	0.11		321
22	Paddy	0.14	0.28	0.12	600	
	Chilli	3.30	4.05	0.84		
23	Paddy	0.26	0.08	0.03	100	

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
24	Paddy	0.26	0.30	0.10	100	
25	Pepper	109	178	250	100	
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		
26	Paddy	0.26	0.30	0.10	250	
27	Pepper	109	208	250	100	
	Nutmeg	1087	1250	1667		
28	Paddy	0.16	0.21	0.10	100	
29	Paddy	0.26	0.18	0.10		
30	Cardamom	65.2	150	100		
	Clove	652	1250	1250		
	Nutmeg	1087	1250	1667		
31	Paddy	0.26	0.30	0.10	350	
32	Pepper	109	250	250		
	Banana	413	575	500		
	Clove	652	1250	1250		
33	Paddy	0.14	0.28	0.07	350	
34	Cardamom	41.1	141	100	100	
	Pepper	109	250	250		
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
35	Cardamom	65.2	125	128	350	
	Cocoa	435	400	467		
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		
36	Cardamom	65.2	150	100		91.7
	Cocoa	435	400	467		
	Clove	652	1250	1250		
37	Cardamom	41.1	55.5	100	250	
	Cassava	2.20	5.06	1.69		
	Banana	413	575	500		
38	Paddy	0.16	0.35	0.09	100	
39	Paddy	0.22	0.32	0.10	350	
40	Paddy	0.16	0.35	0.05	250	
	Cassava	6.11	14.1	4.69		
41	Paddy	0.26	0.30	0.10	100	
42	Paddy	0.14	0.25	0.10	100	
	Cassava	6.11	14.1	4.69		
43	Cardamom	65.2	55.5	100	250	
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		
44	Cardamom	41.1	150	100		550
	Cocoa	435	400	467		
	Clove	652	1250	1250		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
45	Paddy	0.14	0.30	0.10	250	
	Cassava	6.11	14.1	4.69		
46	Cardamom	65.2	72	100	100	
	Pepper	109	250	250		
	Clove	652	1250	1250		
47	Cardamom	41.1	150	100		91.7
	Pepper	109	250	250		
	Cocoa	435	400	467		
48	Cardamom	65.2	150	100	350	
	Nutmeg	1087	1250	1667		
49	Cardamom	65.2	150	71.0		
	Banana	413	575	500		
	Cocoa	435	400	467		
50	Cardamom	46.3	72.0	100	250	
	Pepper	109	250	250		
51	Cardamom	65.2	159	100	100	
	Pepper	109	250	250		
52	Cardamom	65.2	90.0	100		
	Banana	413	575	500		
53	Cardamom	65.2	150	25	100	
	Banana	413	575	500		
	Pepper	109	250	250		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
54	Cardamom	65.2	141	100		
	Pepper	109	250	250		
55	Cardamom	65.2	90	25	100	
	Pepper	109	250	250		
56	Cardamom	65.2	159	100	250	
	Pepper	109	250	250		
57	Cardamom	65.2	150	100	600	
	Pepper	109	250	250		
58	Cardamom	65.2	150	37		550
	Nutmeg	1087	1250	1667		
59	Cardamom	65.2	150	100	350	
	Pepper	109	250	250		
60	Cardamom	46.3	90.0	100	250	
	Cassava	6.11	14.1	4.69		
61	Cardamom	65.2	150	100		
	Pepper	109	250	250		
62	Cardamom	54.8	176	94.0	250	
	Rubber	131	301	100		
	Nutmeg	1087	1250	1667		
63	Cardamom	54.8	176	48.0		
	Pepper	109	250	250		
	Nutmeg	1087	1250	1667		

(Appendix IV (2)- continued)

Sample No.	Crops	N (g plant^{-1})	P (g plant^{-1})	K (g plant^{-1})	Liming material (kg ha^{-1})	
					Lime	Dolomite
64	Cardamom	50.9	192	100	100	
	Pepper	109	250	250		
65	Pepper	68.5	208	62.5	250	
	Nutmeg	1087	1250	1667		
	Clove	652	1250	1250		
	Cassava	6.11	14.1	4.69		
66	Cardamom	35.2	159	100	600	
	Pepper	109	250	250		
	Banana	413	575	500		
67	Arecanut	117	200	233	350	
	Cassava	6.11	14.1	4.69		
68	Cardamom	65.2	141	83.0	100	
	Pepper	109	250	250		
	Cassava	6.11	14.1	4.69		
69	Cardamom	35.2	150	25.0	600	
	Clove	652	1250	1250		
70	Cardamom	65.2	150	100	600	
	Pepper	109	250	250		
	Cassava	6.11	14.1	4.69		
71	Cardamom	35.2	150	100		321
	Cassava	6.11	14.1	4.69		

(Appendix IV (2)- continued)

Sample No.	**Crops**	**N (g plant^{-1})**	**P (g plant^{-1})**	**K (g plant^{-1})**	**Liming material (kg ha^{-1})**	
					Lime	**Dolomite**
72	Pepper	58.7	208	208	350	
	Clove	652	1250	1250		
	Cassava	6.11	14.1	4.69		
73	Cardamom	41.1	150	100	600	
	Clove	652	1250	1250		
74	Paddy	0.24	0.30	0.10	250	
75	Banana	293	673	125	350	
	Cassava	6.11	14.1	4.69		
76	Paddy	0.19	0.30	0.10	600	