ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF NORTH CENTRAL LATERITES (AEU 10) IN THRISSUR DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

By

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THESIS

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DECLARATION

I, hereby declare that the thesis entitled **'Assessment of soil quality in the post flood scenario of North Central Laterites (AEU 10) in Thrissur District of Kerala and mapping using GIS techniques'** is a bona-fide record of research done by me during the course of study and the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **'Assessment of soil quality in the post flood scenario of North Central Laterites (AEU 10) in Thrissur District of Kerala and mapping using GIS techniques'** is a record of research work done independently by **Riaj Rahaman (2018-11-151)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Riaj Rahaman

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Introduction

1. INTRODUCTION

Soil quality can be described as suitability of soil for use or "the capacity of soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem” (Larson and Pierce, 1991). The functions include sustaining plant growth by supplying adequate nutrients and water to plant, filtering and cleaning water, maintaining soil temperature, recycling of essential plant nutrients and providing shelter to soil flora and fauna.

The functioning of specific kind of soil depends on soil properties, environmental factors and soil management practices. So, it is necessary to identify the set of sensitive soil attributes which directly or indirectly reflect on soil quality and expresses how well a soil can function. The attributes can be physical, chemical, and biological characteristics. Physical attributes which include bulk density, particle density, water holding capacity, porosity, texture and structure depend on composition of soil, added organic matter and physical operations such as tillage. Soil pH, electrical conductivity, effective cation exchange capacity, available nutrients and heavy metals are the properties associated with biochemical activity, fertility status, element toxicity or soil contamination. Organic carbon, microbial community structure and activities of different soil enzymes give an estimate of soil biological activity.

Dynamic properties of soil significantly change under extreme environmental condition and therefore affect soil quality. Flooding shifts a well aerated soil to partially or completely reduced state, causing physical modification and altered biochemical activities. The removal of nutrient rich upper layer from upstream and deposition of sediments in downstream region causes redistribution of functional plant nutrients. Flood affects structural stability, changes soil fertility, alters the dominance of existing flora and triggers strong disturbance (Walker, 2012).

Soil saturated with water restricts penetration of oxygen resulting in a reduced layer devoid of oxygen. The degree of reduction can be evaluated by measuring redox potential, which drastically decreases under submergence affecting nutrient availability. Drop in redox potential is strongly associated with the increased activity of dehydrogenase enzyme under flooded condition (Wolinska and Stepniewska, 2012). Soil microbes quickly respond to changes in soil environment; thereby acting as early indicators of soil quality. Microbial respiration increases evolution of CO_2 which decreases the soil pH immediately after flooding, which increases thereafter as CO_2 diffuses away. Very few microbes, especially the facultative and obligate anaerobes can grow and reproduce under anaerobic environment; hence metabolic activity within the soil significantly decreases after flooding.

The agro-ecological unit (AEU 10) designated as North Central Laterites is delineated to represent midland laterite terrain of Kerala. The unit is spread over 62 *panchayats*, three municipalities, and a corporation in Thrissur and Palakkad districts and covers 4.41 per cent of geographical area of the state (Nair *et al.*, 2011). Soils developed under warm and humid climate are gravelly, strongly acidic, poor in silica, with dominance of kaolinitic clay, often underlain by plinthite. Heavy rainfall and excessive weathering leaches basic cations like calcium, magnesium and potassium leaving behind material rich in sesquioxides.

During August, 2018, the state tackled a devastating flood that caused deleterious after effects on the environment. The deluge had triggered great variation in the soil environment with drastic changes in soil fertility posing threat to crop productivity. Standard references and thresholds for soil quality indicators need to be established in order to evaluate and quantify the variation that had occurred to the soil due to the flood. Site specific management practices have to be undertaken based on the changes, to restore soil fertility and maintain its productivity. Analysis of soil quality attributes and interpretation of the obtained results plays a key role in formulating management techniques under the prevailing condition. Hence, the present study was undertaken with the following objectives:

- To assess the soil quality of post flood soils of AEU 10 in Thrissur district
- To workout soil quality index
- To develop maps on soil characteristics and soil quality using GIS technique

Review of literature

2. REVIEW OF LITERATURE

Quality assessment of soil has become an important activity in the view of protecting and preserving soil as well as sustaining its function (Nortcliff, 2002). Floods result in drifting of crop residues, removal of surface layer rich in nutrients and organic components from the uplands, water stagnation and deposition of alluvium in low lands. Change in hydrological conditions in soil due to flooding cause alterations in soil environment. Hence, urgent attention to restore and sustain soil productivity is required.

The literature relevant to the present investigation are reviewed in this chapter.

2.1. Soil quality

The term ‘soil quality’ was introduced by Mausel (1971). It mainly refers to the dynamic properties of surface soil that can be strongly altered by management practices. It is the umbrella term for overall soil health and describes several functions of soil, related to the fitness of the ecosystem, nutrition and quality of crop, the buffering of pollutants and sustaining food and fiber production (Smith and Doran, 1996).

Quality assessment of soil aims at the responses of soil biological, chemical, and physical properties, their interaction and processes by anthropogenic activities over time (Karlen *et al.,* 2001). Arshad and Coen (1992) reported that the key physical and chemical parameters for assessment of soil quality are depth of soil, hydraulic conductivity, aggregate stability, water holding capacity, bulk density, organic matter, soil pH, electrical conductivity, cation exchange capacity and exchangeable sodium percentage. According to Filip (2002) microbial biomass, dehydrogenase activity, N_2-fixing bacteria, soil respiration and humication activity were the biological properties found as the most sensitive quality parameters.

Quantification of soil quality can be made by expressing soil quality as a function of measurable soil properties (Larson and Pierce, 1991). A perfect soil quality index may consist of three component goals namely agronomic sustainability, environmental quality, and socio-economic viability (Andrews *et al.,* 2002). Appropriate indicators of soil quality with maximum variation in the data set can be selected with principal component analysis (PCA) as a statistical tool (Navas *et al.,* 2011).

2.2. Effect of flood on soil properties

2.2.1. Soil physical properties

Degradation of the soil structure as a result of constant wetness and anaerobiosis contribute to compaction of soil and reduction of the volume of macro pores, which restricts free movement of water through the soil profile. Soil therefore becomes excessively wet and unfit for crop production (Lal, 1991). Flood water increase absorption of solar radiation by the soil as it darkens soil colour but is inversely related to the thermal conductivity (k) of soil and consequently thermal diffusivity (k/C) (Ponnamperuma, 1984).

Flood water decreases the soil aeration status as air is replaced by water leading to limited gas diffusion through the soil, while the increase in temperature and decrease in oxygen diffusion rate increase demand for O_2 in the soil (Brzezinaska *et al.,* 1998). Oxygen deficiency or exclusion in submerged soils occur within six to ten hours of flooding. Microorganisms and plant roots use up the oxygen trapped in the soil or present in the water molecules within few hours of flooding (Kreuzwieser and Rennenberg, 2014). The oxygen movement through the flood water is usually much slower than the rate at which oxygen is reduced in the soil (Fageria *et al*., 2011). Further, the percolation rate decreases with flooding because of physical and chemical changes such as swelling, dispersion, disintegration of soil aggregates, reduction of soil pores by microbial activity, and organic-matter decomposition, which reduces the binding effect of aggregates and causes the soil to seal off.

Texture of soil changes after flooding as the top soil rich in nutrients from upper river stream is washed away, while the arable soil in central and lower stream is covered by drift soil (Elhottova *et al.,* 2005). During flood, soil colloids absorb water and swell; the extent of swelling depends on the amount of clay present, type of clay minerals and nature of exchangeable cations (Saha, 2004). Swelling is comparatively more in soil with higher clay content, expandable layer silicate clay minerals and higher exchangeable sodium than acid and calcareous soil or the soil with less clay content and non-expandable layer silicate minerals (Ponnamperuma, 1984).

Increase in water content increases the thickness of water film around the soil particles. Beyond a certain limit (liquid limit) cohesive force decreases rapidly, resulting in weakening of shear strength of soil which consequently disrupts soil aggregates. Uneven swelling due to pressure of entrapped air and dilution of soil solution causes deflocculation of clay colloid. Dispersion of soil particles block the pores and limits movement of water through the soil (Saha, 2004).

Aggregate stability of soil is influenced by changes in the redox potential. Increasing concentration of soluble Mn^{2+} and Fe^{2+} under submergence is negatively correlated with the aggregate stability of soil. As redox potential decreases, the aggregate stability of soil also decreases. The decline in aggregate stability under reduced condition, might be due to exchange of cations that stabilize soil aggregates, such as Ca, Mg, and K between the soil and soil solution. Cultivated soils are more prone to decrease in aggregate stability than uncultivated soil due to soil reduction, where the decrease in aggregate stability was up to 21 per cent (De-Campos *et al.*, 2009).

2.2.2. Electrochemical properties

The most important changes that occur in flooded soils are pH, redox potential, and ionic strength or electrical conductivity. Electrochemical changes caused by soil submergence has a direct impact on soil chemical diversity. Flooding benefits rice plant by enhancing soil pH, microbial activity and stabilizing soil chemical fertility (Sahrawat, 1998).

2.2.2.1. Soil pH

Soil pH is a key factor which determines the solubility of minerals, availability of nutrient elements for plant uptake, the fate of many soil contaminants, their degradation and future movement through the soil. The pH of acidic soils increase and alkaline soils decrease as a result of flooding. Soil pH decreases sharply just after submergence, thereafter increases asymptotically and stabilizes within the range of 6.7 to 7.2. Initial decrease might be due to the increased concentration of CO_2 resulting from aerobic respiration of soil microbes which subsequently increase when partial pressure of CO_2 decreases (Ponnamperuma, 1972). The pH of flooded soil is sensitive to the concentration of CO_2. Carbon di oxide produced as a result of microbial respiration, anaerobic fermentation and restricted diffusion under flooded condition, enhance the production of carbonic acid leading to decreases in pH of alkali and calcareous soil (Sahrawat, 2012).

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H^+ + HCO^-$$

Flooding produces large quantities of ferrous iron and sparingly soluble ferrous salts mainly ferrous carbonate and ferrous hydroxide which buffers the soil pH around neutrality i.e; raises the pH of acid soil whereas decreases the pH of alkaline soil (Kashem and Singh, 2001). Low levels of Fe (III) oxides, and possibly SO_4, in relation to soil acidity tend to be a major cause of the lack of pH increase due to soil reduction following flooding in well-drained acid sulphate soil. The soil pH in such soil is maintained below 5 even after prolonged flooding (Konsten *et al.*, 1994).

2.2.2.2. Electrical conductivity

Electrical conductivity (EC) is a function of ionic concentration in the soil and thus correlated with dissolved solutes, such as ions and salts. Exogenous influx of salts, ions and total dissolved solids brought into the soil by the flood significantly increase the electrical conductivity of soil. In order to prevent salinity hazard to plants by excessive accumulation of salts and ions, regular flooding should be controlled to maintain the EC value below 2 dS m^{-1} (Akpoveta *et al.*, 2014).

According to Ponnamperuma (1972) electrical conductance of soil solution increases immediately after submergence and thereafter drops to a stable value. Initial increment is contributed by the release of Fe^{2+} and Mn^{2+} from insoluble Fe (III) and Mn (IV) oxide hydrates, accumulation of NH^{4+}, HCO_3^- and dissolution of $CaCO_3$. But later Fe^{2+} and Mn^{2+} was found to precipitate as $Fe_3O_4.nH_2O$ and $MnCO_3$ respectively resulting in subsequent decline in EC. Kalshetty *et al.*, 2012 observed an increase in electrical conductivity in flooded lands due to the addition of total dissolved solids

2.2.2.3. Redox potential

One of the most important distinguishing feature of flooded soil is drop in redox potential (Eh) which determines the extent of soil reduction. Wlodarczyk (2002) observed a gradual decline of redox potential from 435 mV to as low as 7 mV in an incubation study after seven days of flooding. Initially the decrease in redox potential is due to the release of reducing substances and thereafter the rate and magnitude of reduction depends on kind and amount of soil organic matter, temperature and duration of submergence. Neutral soils rich in organic matter accelerate the rate of reduction whereas it is retarded in acid soil with low organic matter (Ponnamperuma, 1972). Drop in Eh is maximum at the temperature of 25°C, fluctuation of temperature above or below this slow down the decrement rate but varies with soil (IRRI, 1967). Inorganic iron and manganese exhibited significant role in buffering redox potential; manganese in the range of 100 to -50 millivolts and iron in the range of -50 to -200 millivolts. Rising concentration of reducible ferric iron improves the buffering effect and retards the fall of redox potential after flooding. Unger *et al.*, (2009) categorised soil as oxic (>414 mV), suboxic (414-120 mV) and anoxic (<120 mV) depending upon the redox potential and the lowest value (anoxic) was observed at five weeks of flooding.

2.2.3. Soil chemical properties

Soil tolerance against chemical disturbance caused by flooding depends on the colloidal properties and textural class of the soil. The removal of nutrient rich top soil or the accumulation of silt causes alterations in the soil chemical properties. Silt improves soil texture which is the positive aspect of floods on soil quality. Flood water may also flush out soluble salts and reduce salinity of the soil. On the contrary, deposition of sandy coarse materials may have localized detrimental effects on soil quality as it reduces the water holding and nutrient retention capacity.

2.2.3.1. Macro nutrients

The most significant change in the soil in the post flood scenario is the alteration of the soil's root zone from an aerobic environment to an anaerobic or near-anaerobic environment in which oxygen is absent or limited. Due to the absence of oxygen required for the microbial conversion of ammonia into nitrate, nitrogen mineralization under anaerobic soil conditions can not proceed beyond the ammonium (NH^{4+}) phase. Thus, degradation of organic matter that allows ammonium ions to be released into the soil solution continues at a slower rate in a waterlogged soil (Patrick *et al.*, 1996). The NO_3^- nitrogen is lost from the soil by denitrification, converted to NH^{4+} nitrogen or leaches through the soil. The trend of this transformation is strongest after five weeks of flooding (Unger *et al.*, 2009). Prolonged submergence can increase the concentration of ammonia to toxic level; however, toxicity threshold vary with the plant species (Sahrawat, 2004).

When the molecular oxygen level within the soil decreases as a result of flooding, obligate respiratory bacteria belonging to the genera *Agrobacterium, Bacillus, Paracoccus, Pseudomonas* and *Thiobacillus* use up the oxygen present in nitrates as a terminal electron acceptor reducing it to NO, N_2O, or N_2. Denitrification is the major cause of nitrogen loss in flooded soil (Fitter and Hay, 2012).

Denitrification contributes a significant loss of nitrogen due to the presence of easily decomposable carbon resulting from the killing of vegetation and higher air temperature above 20°C under submergence (Eulenstein *et al.*, 1998). Das (2013) observed that, the rate of nitrification increased in oxidised surface layer of waterlogged soil where ammonia converted to nitrate; whereas, nitrate reduced to N_2 in underlying anoxic layer, which increased loss of nitrogen from soil. Temperature has a significant influence in the release of ammonia in flooded soil. High temperature and excessive concentration of NH_4^+ ion in soil solution accelerate its loss through volatilization (Hayashi *et al.*, 2006).

Flooding has a great impact on soil phosphorus availability. Phosphate activity in flooded soils is considerably different from that in aerated soils. Under anaerobic conditions, ferric iron is reduced to more soluble ferrous iron within a few days of flooding, thereby releasing occluded phosphates or phosphates co-precipitated with ferric oxides (Zhang *et al.,* 2003). Due to the reduction of ferric phosphate to the more soluble ferrous form and the hydrolysis of phosphate compounds, the concentration of available phosphate in flooded soil increases significantly. Reductive dissolution of Fe(III) oxides and release of P under anoxic environment depends on the degree of P saturation in soil, ratio of total Fe and total P, molar ratios of oxalate extractable Fe and P and bicarbonate-dithionite extractable Fe and P (Gasparatos *et al.,* 2019). Sah and Mikkelsen (1989) reported that the sorption of phosphorus under submergence mainly depends on soil organic matter conten and temperature. Soils rich in organic matter exhibited higher phosphorus adsorption at elevated temperature under flooded condition. When the flooded soil is drained the reaction between phosphorus and soil mineral leads to phosphorus immobilization.

Loss of soil organic matter during flooding accounted for decline in cation exchange capacity as organic matter contributes to CEC by increasing adsorption sites for cations (Oorts *et al.,* 2003). Flooding significantly increases the concentration of exchangeable Fe and Mn, due to reduction which displace other cations from the exchange sites causing its loss (Phillips and Greenway, 1998). Increase in plant available potassium was observed in flooded soil by Eulenstein *et al.* (1998) due to the expansion of smectite clay and release of potassium.

2.2.3.2. Micro nutrients

Under submergence less soluble ferric ions (Fe^{3+}) are reduced to more soluble ferrous form (Fe^{2+}) in iron-rich acid soil resulting in Fe toxicity. Excessive absorption of Fe^{2+} and their translocation into leaves increases production of toxic oxygen radicals causing damage of cell and develop visual symptoms like ‘bronzing’ in rice plant with subsequent yield loss (Becker and Asch, 2005). The degree of reduction depends on soil organic matter content which serves the micro-organisms as an energy source. Increasing activity of soil micro-organism produces certain enzyme that reduces ferric iron to the ferrous form or the reduced organic products of microbial decomposition can chemically reduce iron. The reduction is more prominent in acid soil after flooding as higher activity of hydrogen ion leads to release more iron from crystalline form and present as reducible iron oxide in the soil (Fageria *et al.,* 2008). According to Sahrawat (2010) Fe and Mn are found in elevated concentration in flooded soils but the toxic solubility of these elements are reduced due to increased pH. However availability of S is lowered as a result of reduction of sulphate to sulphide in anaerobic condition.

Flooding enhances the production of hydrogen sulphide (H_2S), resulting from sulphur reduction under anaerobic condition. The extent of reduction is negatively correlated with soil pH and positively correlated with sulphate concentration in soil (Watanabe and Furusaka, 1980). Weber *et al.* (1998) recorded very high concentration of zinc in the surface soil compared to sub surface soil in the post flood soil analysis which was attributed to higher humus in surface soil with higher sorption capacity.

2.2.3.3. Heavy metals and other contaminants

At higher pH under flooded condition bio availability of metal ions are significantly reduced thus restricting their transport to plant.

Bioavailability of heavy metals under anoxic environment mostly depends on the concentration of sulphides, oxides and hydroxides of iron and manganese with which they form stable complexes. Poot *et al.* (2007) analysed acid volatile sulphides (AVS) and simultaneously extracted metals (SEM) as a measure of reactive fraction of sulphides and metals in sediment and observed that in areas with low velocity of flood water, more fine particles, organic matter associated sulphides and metal ions were deposited compared to that of fast flowing areas.

Floodplain sediments serve as a sink for organic pollutants such as polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls and organochlorine pesticides (Hilscherova *et al.,* 2007). Fine textured sediments deposited after flooding enhance the sorption of toxic metal ions and PAH which reduce their bioavailability and transport to deeper soil layers (Maliszewska-Kordybach *et al.,* 2011).

2.2.4. Soil biological properties

Analysis of soil microbial activity and their diversity act as early indicators of soil quality deterioration or improvement as soil functioning, regulation of nutrient recycling and sustaining soil fertility is governed largely by the decomposition activity of the micro flora (Anderson, 2003).

2.2.4.1. Microbial community structure

Changes in soil microbial community structure is a common phenomena when the soil environment shifts from aerobic to anaerobic, since microbes are very sensitive to environmental disturbance. A smooth shift from aerobic respiration to anaerobic fermentation was observed in flooded soil by Parent *et al.* (2008) due to the increasing number of facultative anaerobes. Initially the changes in microbial community structure was attributed by the opportunistic growth of microorganism (*r*-strains) and finally the changes was stabilized due to the abundance of *k*-strains (Wilson *et al.*, 2011).

Soil water regime had a direct effect on colonization of plant roots by arbuscular mycorrhizal fungi. The colonization was found maximum under non-flooded condition and was reduced to 2 to 12 per cent under submergence regardless of differences in soil properties (Solaiman and Hirata, 1995).

Fungi have an important role in initial decomposition of organic matter in flooded soil, thereafter their activity is drastically reduced. Germination of spores of most of the seed-borne fungi was restricted in flooded soils and thus, had an effective control over fungal pathogen (Watanabe and Furusaka, 1980). Phospholipid fatty acids (PLFAs) are major constituents of the cell membranes of all microorganisms. Analysis of soil extracted PLFA gives an estimate of viable microbial community in soil (Rinklebe and Langer, 2006), which is highly sensitive to management practices. Bossio and Scow (1998) recorded consistent reduction in monounsaturated fatty acids as well as total phospholipid fatty acids due to flooding compared to non-flooded soil. Monounsaturated fatty acids are highly substrate dependent; hence, the values decrease under stressed condition. Under stagnant flooding the level of monounsaturated fatty acids were significantly lower than periodic flooding (Unger *et al.*, 2009).

2.2.4.2. Microbial biomass

A sharp decrease in microbial biomass and microbial markers for aerobic bacteria, gram-negative bacteria, gram-positive bacteria, and mycorrhizal fungi was reported by Unger *et al.* (2009) as a result of stagnant flooding. A significant increase in total microbial biomass was observed in arable land; whereas, in meadow soil covered with layer of sediment, the total microbial biomass as well as its active part was decreased. Limited oxygen supply diminished the microbial population. However, the proportion of active / total biomass in flooded soil was higher than non-flooded soil (Elhottova *et al.*, 2005).

The amount of release of microbial biomass carbon (C_{BIO}) and microbial biomass nitrogen (N_{BIO}) was not much affected by degree of saturation of soil. When the water content of a saturated soil increased from 44 per cent to 55 per cent extractable carbon remained unaffected in both unfumigated and fumigated soil, while extractable nitrogen increased significantly as the water content increased. The magnitude of increment was similar in fumigated and unfumigated soil due to increased extractability of NH_4 -N when the water plus extractant: soil ratio rises in both the case, resulting in a small increase in N_{BIO} (Witt *et al.*, 2000).

2.2.4.3. Organic carbon

Total organic carbon contributes to acidity through the contributions of organic acids and biological activities. A small decline in total organic carbon was found in flood-affected farmlands, which may be due to leaching loss of organic acids and humus (Akpoveta *et al.*, 2014). Flooding significantly increases concentration of soluble organic carbon (SOC) in soil solution and thereby increasing their leaching loss from the soil. Leaching loss of SOC was recorded as 399 mg kg^{-1} after 12 weeks of flooding, compared to 99 mg kg^{-1} in normal soils (Wang and Bettany, 1993).

Flood affected soil under anaerobic condition has a negative impact on degradation of lignin and phenolic compounds. Therefore accumulated phenolic compounds can bind with proteins and amino acids and form resistant humic acid polymer which are hard to microbial transformation. Moreover, soluble phenolic compounds having higher protein binding capacity are completely lost from the soil by leaching (Unger *et al.,* 2009).

2.2.4.4. Microbial activity

Flood water carries a huge quantity of alluvial sediment. The organic matter fraction present in the sediments serve as easily decomposable substrate to microbes and enhance their activity in the soil. A significant increase in soil enzyme activity was observed in flooded soil compared to non-flooded soil; especially the enzymes involved in carbon cycle such as invertase, β-glucosidase, dehydrogenase and those involved in sulphur cycle such as arylsulfatase (Gelsomino *et al.*, 2006). Gonzalez Mace *et al.* (2016) reported that, effect of flood on soil micro-organisms, its activity and functioning was more pronounced soon after flooding and recovered rapidly resulting in nutrient limitation. Degradation of recalcitrant compounds like lignin, chitin increased immediately after flooding by the increased activity of soil enzymes. According to Ferronato *et al.* (2019) biochemical reactions leading to SOM degradation are influenced by the soil hydro period, which hinder the activation of enzymes and microbial stabilization. Variety of the organic compounds are fermented by methanogen bacteria and oxidised completely to CO_2, thereafter partially or completely reduced to CH_4. The ratio of carbon dioxide to methane, changes with the oxidation state of the substrate (Buresh *et al.*, 2008).

The major biochemical transformations in flooded soils can be considered as a series of successive oxidation-reduction reactions mediated by various types of bacteria. Aerobes are replaced by facultative and obligatory anaerobes under oxygen deficient condition owing to flood. Dehydrogenase is a respiratory enzyme, activity of which represents the metabolic function of the entire bacterial population. The activity of the enzyme increases with decreasing redox potential. A substantial increase in dehydrogenase activity was observed in flooded soil and was significantly affected by the removed electron during oxidation of organic matter, which drives redox processes in soil (Sahu *et al.,* 2015). Aerobic respiration is energetically more efficient than anaerobic respiration. Dehydrogenase enzyme activity sharply increased at oxygen diffusion rate below 15µg m^{-2} s^{-1} (Brzezinaska *et al.,* 1998). Maximum activity of dehydrogenase enzyme was observed in laterite soil after 20 days of flooding. The activity of enzymes significantly increased with clay content whereas decreased with increasing silt content under flooded condition (Wlodarczyk *et al.,* 2002).

A gradual increase in β-D-glucosidase activity was observed in flooded soil which was attributed to the accumulation of easily oxidizable intermediates like acetate and propionate. The activity of alkaline and acid phosphatase enzymes were reduced after submergence, and increased due to subsequent drainage (Sahu *et al.,* 2015). Pedrazzini and McKee (1984) reported that, activity of alcohol dehydrogenase (ADH) enzyme which indicates the degree of oxygen deficiency encountered by the plant, increases soon after flooding and slowly declines thereafter. The decrement may be attributed to the development of excess aerenchyma tissue by the plant which enhances oxygen movement.

In flooded soil, the rate and amount of nitrogen fixation is variable in different soil layers. Nitrogen fixation in surface layer is performed by aerobic nitrogen fixers such as *Azotobacter,* contributing considerably a higher amount of nitrogen to the soil; however a minor contribution was observed by obligate anaerobes such as *Clostridium* in underlying anaerobic layer (Evans and Barber, 1977). The products of anaerobic decomposition of cellulose move from bottom to the surface layer and are utilized by aerobic heterotrophic nitrogen fixers. Concentration of CO_2 markedly increases in flooded soil, stimulating the activity of nitrogenase enzyme and biological nitrogen fixation (Das *et al.*, 2011). Nitrogen economy of flooded soil is not solely contributed by microbial nitrogen fixation, a larger fraction of the fixed nitrogen also accumulate as soil organic nitrogen due to slow mineralization process. Restricted aeration significantly reduce the rate of decomposition of organic nitrogenous compounds which prevent rapid turnover of the soil nitrogen (Kogel-Knabner *et al.,* 2010).

Materials and methods

3. MATERIALS AND METHODS

The present study entitled "Assessment of soil quality in the post flood scenario of North Central Laterites (AEU 10) in Thrissur District of Kerala and mapping using GIS techniques" was conducted in the Department of Soil Science and Agricultural Chemistry, College of Horticulture, Vellanikkara during 2018-2020. The study included initial survey to identify the flood affected areas of AEU 10 in Thrissur district, collection of geo-referenced soil samples, laboratory analysis and developing maps for soil quality attributes using GIS software.

3.1. Sampling location

The study area was demarcated using the map of Agro-ecological units of Thrissur District of Kerala and the location of sampling points are depicted in Plate 3.1. The Agro-ecological unit (AEU 10) designated as North Central Laterites represents midland laterite terrain. The unit is spread over 62 *panchayats*, 3 municipalities and a corporation in Thrissur and Palakkad districts and covers a land area of nearly 1,71,470 ha (Nair *et al*., 2011). The landform is generally undulating to rolling with occasional low hills with plinthite occurring at various depths.

Details of flood affected *panchayats* in Thrissur District was collected from the office of the Principal Agricultural Officer, Thrissur. Eleven *grama panchayats* were identified to be worst affected by the deluge of August 2018 in AEU 10. Further the details of flood affected areas, name of farmers and extent of crop affected were collected from the respective *panchayat Krishi Bhavans.* An initial survey was conducted in the study area to identify the flood affected cropped areas and the major crops affected. Composite surface soil samples (0-20 cm) were collected from the fields under major crops from all the affected *panchayats.* A total of hundred geo-referenced soil samples were collected to represent the flood affected areas of AEU 10 in Thrissur district. The details of sampling locations are given in Table 3.1.

3.2. Collection of soil samples

Composite samples were collected from the farmers' fields. After clearing the debris a 'V' shaped cut was given in the soil to a depth of 20 cm and a slice of 2.5 cm thickness was scraped from the well cut side and collected into polythene bag (Plate 3.2 and 3.3). Around five samples were collected from each location and mixed thoroughly to make a composite, representative sample.

Core samples were collected from each location to determine bulk density of soil. Natural soil clods of >5 mm diameter were also collected for analysis of aggregate stability.

3.3. Depth of alluvium deposition

Depth of flood alluvium deposited was recorded during sample collection from the farmers' fields (Table 3.1).

Table 3.1. Details of sampling locations

Name of *panchayat* and number of samples	Sample No	Latitude	Longitude	Altitude (m)	Crop(s)	Depth of flood alluvium (cm)
Kuzhur (21)	1	10°12.431′	76°17.774′	27.6	Banana	3
	2	10°12.391′	76°17.730′	28.8	Banana	2
	3	10°12.279′	76°17.783′	28.5	Nutmeg	2
	4	10°12.270′	76°17.863′	31.8	Coconut	3
	5	10°12.095′	76°17.844′	30.6	Banana, Nutmeg	3
	6	10°12.034′	76°17.990′	30	Nutmeg, Banana, Coconut	3
	7	10°11.956′	76°18.004′	25.5	Banana, Coconut	2
	8	10°11.826′	76°18.036′	21.9	Coconut, Nutmeg, Banana	2
	9	10°11.724′	76°18.072′	20.1	Banana	30
	10	10°11.593′	76°18.062′	20.4	Banana, Nutmeg	4
	11	10°11.460′	76°18.007′	20.4	Nutmeg, Banana,	30
	12	10°11.337′	76°17.964′	19.8	Banana	30
	13	10°11.472′	76°17.850′	18	Banana, Coconut	30
	14	10°11.823′	76°17.808′	16.8	Nutmeg, Areca nut	30
	15	10°11.924′	76°17.814′	16.5	Nutmeg, Coconut	3
	16	10°11.987′	76°17.720′	16.5	Nutmeg, Banana	30
	17	10°11.900′	76°17.682′	19.5	Nutmeg, Banana	2
	18	10°11.817′	76°17.626′	18	Nutmeg, Banana	30
	19	10°11.701′	76°17.649′	17.7	Nutmeg	30
	20	10°12.003′	76°17.861′	18	Banana, Nutmeg	2
	21	10°12.092′	76°17.859′	20.1	Banana, Nutmeg	5

Name of *panchayat* and number of samples	Sample No	Latitude	Longitude	Altitude (m)	Crop(s)	Depth of flood alluvium (cm)
Meloor (22)	22	10°17.958′	76°21.860′	58.5	Coconut	5
	23	10°17.967′	76°21.938′	38.1	Coconut	5
	24	10°18.504′	76°23.278′	30.9	Banana	30
	25	10°18.277′	76°23.072′	30.6	Banana	4
	26	10°17.991′	76°23.119′	33.9	Banana, Coconut	5
	27	10°17.698′	76°23.099′	21.3	Coconut	6
	28	10°17.552′	76°22.794′	14.1	Nutmeg	30
	29	10°17.531′	76°22.789′	9	Coconut	5
	30	10°17.509′	76°22.689′	5.1	Coconut, Arecanut, Banana	5
	31	10°17.584′	76°22.553′	5.7	Coconut	5
	32	10°17.535′	76°22.541′	6.6	Coconut	4
	33	10°17.826′	76°22.159′	7.8	Banana	4
	34	10°17.906′	76°22.108′	7.8	Banana	4
	35	10°18.261′	76°21.168′	6.6	Coconut	30
	36	10°18.292′	76°21.154′	8.1	Nutmeg	30
	37	10°17.757′	76°20.853′	15	Banana	4
	38	10°17.746′	76°20.904′	10.8	Nutmeg, Arecanut	4
	39	10°17.887′	76°20.813′	9.3	Banana	30
	40	10°18.186′	76°20.961′	4.8	Banana, Coconut	25
	41	10°17.496′	76°21.090′	3.6	Arecanut	30
	42	10°17.470′	76°21.182′	4.2	Coconut, Arecanut	35
	43	10°17.349′	76°21.384′	6.3	Banana	8

Name of *panchayat* and number of samples	Sample No	Latitude	Longitude	Altitude (m)	Crop(s)	Depth of flood alluvium (cm)
Annamanada (12)	44	10°15.948′	76°17.714′	42	Nutmeg	6
	45	10°16.106′	76°17.750′	31.8	Nutmeg, Coconut	35
	46	10°15.910′	76°17.787′	29.1	Nutmeg	28
	47	10°15.751′	76°17.896′	34.2	Coconut, Arecanut	4
	48	10°15.714′	76°17.795′	30	Tapioca, Coconut	7
	49	10°15.770′	76'17.812′	27.9	Areca nut Nutmeg	8
	50	10°15.768′	76°17.995′	28.5	Nutmeg, Arecanut, Coconut	7
	51	10°15.680′	76°18.089′	25.8	Nutmeg, Arecanut, Coconut	3
	52	10°15.844′	76°18.130′	25.8	Nutmeg, Banana	4
	53	10°15.683′	76°18.184′	28.8	Banana, Coconut	2
	54	10°15.689′	76°18.334′	23.7	Banana	3
	55	10°15.577′	76°18.475′	21.9	Nutmeg, Coconut	6
Kadukutty (13)	56	10°16.614′	76°19.263′	2.4	Banana, Arecanut	2
	57	10°16.715′	76°19.283′	3.9	Nutmeg, Arecanut, Coconut	3
	58	10°16.867′	76°19.351′	1.5	Nutmeg, Coconut	7
	59	10°16.917′	76°19.390′	3.3	Coconut	3
	60	10°16.996′	76°19.425′	4.8	Banana	4
	61	10°17.071′	76°19.555′	5.4	Nutmeg, Arecanut	27

Name of *panchayat* and number of samples	**Sample No**	**Latitude**	**Longitude**	**Altitude (m)**	**Crop(s)**	**Depth of flood alluvium (cm)**
	62	10°17.080′	76°19.777′	11.1	Nutmeg, Coconut	3
	63	10°16.707′	76°19.012′	3	Banana	32
	64	10°16.703′	76°18.969′	3.3	Banana	25
	65	10°16.739′	76°18.754′	4.8	Banana, Arecanut	30
	66	10°16.189′	76°19.290′	3.9	Banana	35
	67	10°15.470′	76°19.308′	5.1	Coconut	5
	68	10°15.456′	76°19.250′	56.1	Banana	30
Koratty (3)	69	10°15.235′	76°21.156′	54.3	Nutmeg, Coconut	5
	70	10°15.050′	76°20.988′	40.5	Banana	2
	71	10°15.179′	76°21.127′	27	Banana	30
Alagappanagar (4)	72	10°26.357′	76°16.189′	31.8	Banana, Coconut	5
	73	10°26.397′	76°16.084′	28.2	Banana	30
	74	10°26.296′	76°16.093′	24	Coconut Arecanut	5
	75	10°26.347′	76°15.975′	21.9	Nutmeg, Banana	5
Thrikkur (4)	76	10°26.793′	76°16.260′	18.9	Banana, Coconut	5
	77	10°26.939′	76°16.336′	18.9	Banana, Coconut, Arecanut	5
	78	10°27.002′	76°16.390′	22.2	Banana	3
	79	10°26.629′	76°16.512′	23.1	Banana, Coconut,	5
Kodakara (4)	80	10°21.869′	76°17.505′	38.4	Banana, Coconut	3
	81	10°22.897′	76°17.517′	26.7	Arecanut, Nutmeg, Coconut	3
	82	10°22.758′	76°17.450′	18.6	Banana, Coconut, Arecanut	3
	83	10°22.787′	76°17.350′	16.5	Banana	3

Name of *panchayat* and number of samples	Sample No	Latitude	Longitude	Altitude (m)	Crop(s)	Depth of flood alluvium (cm)
Pudukad (4)	84	10°24.573′	76°16.279′	13.5	Banana, Arecanut	3
	85	10°24.362′	76°16.205′	12.6	Banana, Arecanut, Nutmeg	2
	86	10°24.337′	76°16.167′	11.7	Banana	3
	87	10°24.381′	76°16.142′	12	Banana	3
Chalakudy (7)	88	10°17.659′	76°19.725′	37.8	Banana	25
	89	10°17.710′	76°19.432′	24.6	Nutmeg, Arecanut	5
	90	10°17.662′	76°19.294′	18	Banana, Nutmeg, Coconut	3
	91	10°17.342′	76°19.375′	12.6	Nutmeg, Arecanut	5
	92	10°17.235′	76°19.262′	9.9	Banana	5
	93	10°16.980′	76°18.882′	9.9	Nutmeg, Coconut	6
	94	10°17.077′	76°18.545′	9.9	Coconut	25
Pariyaram (6)	95	10°19.188′	76°25.190′	20.4	Banana	25
	96	10°20.120′	76°23.947′	12.3	Banana	9
	97	10°18.526′	76°23.784′	29.4	Banana, Coconut	30
	98	10°18.163′	76°25.400′	25.5	Nutmeg, Coconut	28
	99	10°17.594′	76°25.450′	20.1	Banana, Coconut, Nutmeg	60
	100	10°17.476′	76°25.679′	18.3	Banana, Nutmeg	60

3.4. Processing of soil samples

Soil samples were air dried under shade, ground using wooden mortar and pestle, sieved through 2 mm sieve and stored for further analysis. For determination of organic carbon, required quantity was ground to pass through 0.5 mm sieve. A separate set of field moist sample was stored in refrigerator at 4°C and all biological parameters were analysed within one week after collection.

3.5. Analyses of soil characteristics

Soil samples were analysed for physical, chemical and biological parameters using standard procedures as detailed below:

3.5.1. Physical attributes

3.5.1.1. Soil physical constants

Keen-Raczkowski box method was used to determine various physical constants of soil (Keen and Raczkowski, 1921). Filter paper of suitable size was placed at the perforated bottom of the box and soil passed through 2 mm sieve was poured slowly and packed by tapping the box until completely full. The box filled with soil was then kept in a tray with 1cm deep water to saturate for 24 hours. The weight of box was recorded before and after filling with soil, and after saturation. The box was again weighed after removing the expanded wet soil. The box and the expanded portion of soil was dried to constant weight at 105°C in hot air oven (Plate 3.4). The data was used to determine different physical constants.

3.5.1.1.1. Particle density (PD)

Particle density of soil was estimated as the ratio of weight of oven dry soil to the volume of soil solid expressed as Mg m^{-3}.

$$\text{Particle density} = \frac{\text{Weight of oven dry soil}}{\text{Volume of soil solid}}$$

3.5.1.1.2.. Porosity

Porosity of soil was obtained from the ratio of pore volume to total volume of soil expressed in per cent (%).

$$\text{Porosity} = \frac{\text{Volume of pore}}{\text{Volume of soil}} \times 100$$

3.5.1.1.3. Maximum water holding capacity (WHC)

Maximum water holding capacity (WHC) of soil was determined as the weight of water held by the soil, when saturated for 24 hours, expressed in per cent (%).

$$\text{Max. WHC} = \frac{\text{Weight of water (after 24 hours saturation)}}{\text{Weight of soil}} \times 100$$

3.5.1.2. Bulk density (BD)

Bulk density of the undisturbed soil was determined from the core sample as the ratio of oven dry weight of soil to the total volume of core sampler and was expressed as Mg m^{-3}.

$$\text{Bulk density} = \frac{\text{Weight of oven dry soil}}{\text{Total volume of soil}}$$

3.5.1.3. Soil moisture content (SMC)

Moisture content was calculated by gravimetric method. Freshly collected samples were dried in oven at 105°C till constant weight was obtained and was expressed in per cent (%) moisture on oven dry basis.

3.5.1.4. Aggregate stability

`Analysis of soil aggregate stability was carried out by wet sieving method using Yoders apparatus (Yoder, 1936). Soil clods of 5-8 mm in size were placed on a set of sieves, arranged in a series from top (5 mm) to bottom (0.1 mm) and fixed in the apparatus (Plate 3.5). The cylinder of the apparatus was filled with salt free water up to the base of the topmost sieve and was allowed to oscillate for 30 minutes with a frequency of 30 cycles per minute. Soil collected in different sieves were weighed after oven drying to constant weight. The fractions of sample retained in different sieves were greater than the respective sieve size, hence mean diameter was taken for calculation and the result was expressed in terms of Mean Weight Diameter (MWD).

$$MWD = \sum_{i=1}^{n} W_i \bar{X}_i$$

Where, W_i, X_i and n are weight of aggregate (g), mean diameter of soil particles in each sieve (mm) and number of sieves used, respectively.

3.5.2. Chemical attributes

3.5.2.1. Soil pH

Soil pH was determined potentiometrically in 1:2.5 soil water suspension with a pH meter after calibrating with standard buffer solutions (Jackson, 1958).

3.5.2.2. Electrical conductivity (EC)

Electrical conductivity was measured with conductivity meter in the supernatant of the soil water suspension (1:2.5) used for pH measurement and expressed in dS m^{-1}. The cell constant was determined with observed conductance of 0.01 N KCl solution (Jackson, 1958).

3.5.2.3. Exchange acidity

Exchange acidity was determined by leaching the soil with 1N KCl to displace exchangeable hydrogen and aluminium ions and the displaced ions were determined by titrating against standard NaOH with phenolphthalein indicator (Reeuwijk, 2002).

3.5.2.4. Available nitrogen (Av. N)

Available nitrogen in soil samples was determined by distilling with alkaline permanganate (0.32%) solution. The ammonia liberated during distillation was absorbed in 25 mL solution of boric acid with mixed indicator and titrated against 0.02N H_2SO_4 to determine the absorbed ammonia (Subbiah and Asija, 1956).

3.5.2.5. Available phosphorus (Av. P)

Available phosphorus content in soil was extracted with Bray No. 1 reagent (Bray and Kurtz, 1945) to obtain acid soluble forms of phosphorus and was estimated colorimetrically at 660 nm by reduced molybdate blue colour method using ascorbic acid as reducing agent (Murphy and Riley, 1962) (Plate 3.6).

3.5.2.6. Available potassium, calcium and magnesium

The available pool of basic cations in soil was extracted with neutral 1N ammonium acetate to determine available potassium (Av. K), calcium (Av. Ca) and magnesium (Av. Mg) in soil (Hanway and Heidel, 1952; Jackson, 1958). The content of potassium was estimated by flame photometry and that of calcium and magnesium by atomic absorption spectrophotometer.

3.5.2.7. Available sulphur (Av. S)

Available sulphur in soil was estimated by turbidimetric method, as proposed by Massoumi and Cornfield (1963) at 440 nm using spectrophotometer with 0.15% $CaCl_2$ as extractant (Tabatabai, 1982).

3.5.2.8. Available micronutrient cations

Available iron (Av. Fe), copper (Av. Cu), manganese (Av. Mn) and zinc (Av. Zn) were extracted by 0.1 M HCl (Sims and Johnson, 1991). The filtrate was analysed for micronutrient cations using atomic absorption spectrophotometer (Plate 3.7).

3.5.2.9. Available boron (Av. B)

Concentration of available boron in soil was extracted with hot water and determined colorimetrically at 420 nm wavelength in a spectrophotometer (Plate 3.8) (Berger and Truog, 1939; Gupta, 1972).

3.5.3. Biological attributes

3.5.3.1. Organic carbon (OC)

Wet oxidation method (Walkley and Black, 1934) was adopted for determination soil organic carbon, in which organic carbon was oxidised to CO_2 using chromic acid and the unused $K_2Cr_2O_7$ was determined by titrating against 0.5 N ferrous ammonium sulphate using ferroin indicator (Plate 3.9).

3.5.3.2. Dehydrogenase activity (DHA)

Activity of dehydrogenase enzyme in soil was estimated by 2,3,5-triphenyl tetrazolium chloride (TTC) reduction method (Casida *et al.*, 1964). The intensity of pink colour developed when TTC is reduced to 2,3,5-triphenyl formazan (TPF) by the activity of dehydrogenase enzyme was determined colorimetrically in spectrophotometer at 485 nm.

3.5.3.3. Microbial biomass carbon (MBC)

Soil MBC was determined by chloroform fumigation extraction method (Jenkinson and Pawlson, 1976) where soil samples were fumigated with ethanol free chloroform for 24 hours. Organic carbon content was extracted with 0.5 M K_2SO_4 from fumigated and unfumigated samples. The extract was treated with 2 mL of 0.2 N $K_2Cr_2O_7$, 10 mL of concentrated H_2SO_4 and 5 mL of ortho-phosphoric acid and warmed in hot plate for half an hour and titrated against ferrous ammonium sulphate using di phenyl amine indicator after adding 250 mL of distilled water (Plate 3.10). The difference in carbon content between fumigated and unfumigated samples gave the measure of microbial biomass carbon.

3.6. Statistical analysis

Analysis of variance (ANOVA) was done using SPSS (version 20) to assess the variations in soil properties with relation to flood affected areas in different *panchayats*. Duncan's multiple range test was used to estimate the significance of difference among mean values of different parameters. Pearson's correlation coefficients were used to determine the strength of relationships among soil properties.

3.6.1. Nutrient Index (NI)

To evaluate the soil fertility status of the flood affected areas, nutrient indices for major nutrients (available N, P and K) were calculated using the equation:

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

(Motsara *et al*., 1982)

Where, N_l, N_m and N_h stands for number of samples falling in low, medium and high category available nutrient status respectively. Table 3.2 and Table 3.3 represents the rating chart for soil test values and nutrient indices.

Table 3.2. Rating for available nutrient content in soil

Available nutrient	**Low**	**Medium**	**High**
Nitrogen (kg ha^{-1})	<280	280-560	>560
Phosphorus (kg ha^{-1})	<10	10.1-24	>24
Potassium (kg ha^{-1})	<116	116-275	>275

Table 3.3. Rating for Nutrient Index (Ramamoorthy and Bajaj, 1969)

Nutrient Index	**Range**	**Interpretation**
Low	<1.67	Low fertility status
Medium	1.67-2.33	Medium fertility status
High	>2.33	High fertility status

3.6.2. Soil Quality Index (SQI)

Soil quality index was determined by following three steps suggested by Raiesi (2017): (1) Selection of minimum data set (MDS) of indicators (2) Scoring of the indicators and (3) Integrating the scores into SQI.

Minimum data set was selected by performing Principal Component Analysis (PCA) on the measured soil attributes using OPSTAT software, COBS&H CCS HAU, Hisar. Principal components for a dataset are linear combinations of variables that account for maximum variance within the entire dataset (Andrews *et al*. 2002). The principal components with eigenvalues >1 (Brejda *et al*. 2000) and explaining at least 5% of the variation in the data (Sharma *et al*. 2005) were selected. The attributes with absolute value within 10% of the highest factor loading in each PC was considered for MDS. Further to reduce redundancy of data multivariate correlation coefficients were determined between attributes in each PC and the indicators with correlation coefficient >0.60 were replaced with single indicator having higher factor loading.

Depending on the contribution of the indicators in the MDS to soil quality they were categorised into (i) More is better (ii) Less is better and (iii) Optimum is better. The observations in each MDS indicator were scored using non-linear scoring and linear scoring methods.

3.6.2.1. Non-linear scores

Indicators were transformed into nonlinear scoring functions using an equation that defined a sigmoidal type curve, with an asymptote tending to 1 and another tending to 0 (Bastida *et al*., 2008):

$$Y = a/(1 + (\frac{x}{x_m})^{b})$$

Where, 'Y' is the non-linear score of each indicator ranging from 0 to 1, a is the maximum value (taken as a = 1) reached by the function, x is the value of the selected indicator and x_m is the mean value of each indicator, b is the slope of the equation and was set as −2.5 for "more is better" and +2.5 for "less is better" functions.

3.6.2.2. Linear scores

Indicators were transformed into linear scores (Liebig *et al*., 2001) by dividing all the observations by the highest observed value for the parameter categorized under

“More is better” and the lowest observed value was divided by all the observations for “Less is better” indicators. For indicators under “Optimum is better” category, observations were scored as “More is better” up to a threshold value and then as “Less is better” above it.

The soil quality index was obtained by summing up the weighted indicator scores of the minimum data set using the function:

$$SQI = \sum_{i=1}^{n} W_i S_i$$

Where, S_i is the score of the variable and W_i is the weighing factor obtained from PCA. The weighing factor for indicators under each PC was obtained by dividing the per cent variation in the total data set explained by that PC by the total per cent variation explained by all PCs with eigen vectors >1.

3.6.3. Relative Soil Quality Index (RSQI)

The deviation in soil quality was measured by computing the relative soil quality index (RSQI) proposed by Karlen and Stott (1994).

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

Where, SQI is the computed soil quality index and SQI_m is the theoretical maximum. The relative performance of each sampling location was rated based on the RSQI as poor (RSQI <50%), medium (RSQI 50-70%) and good (RSQI >70%) (Kundu *et al.*, 2012).

3.7. Generation of maps using GIS technique

Geo referenced thematic maps of important soil quality parameters and soil quality index were prepared using Inverse Distance Weighted (IDW) technique as spatial analyst tool in ArcGIS 10.1 software.

Plate 3.1. Sampling locations in the study area

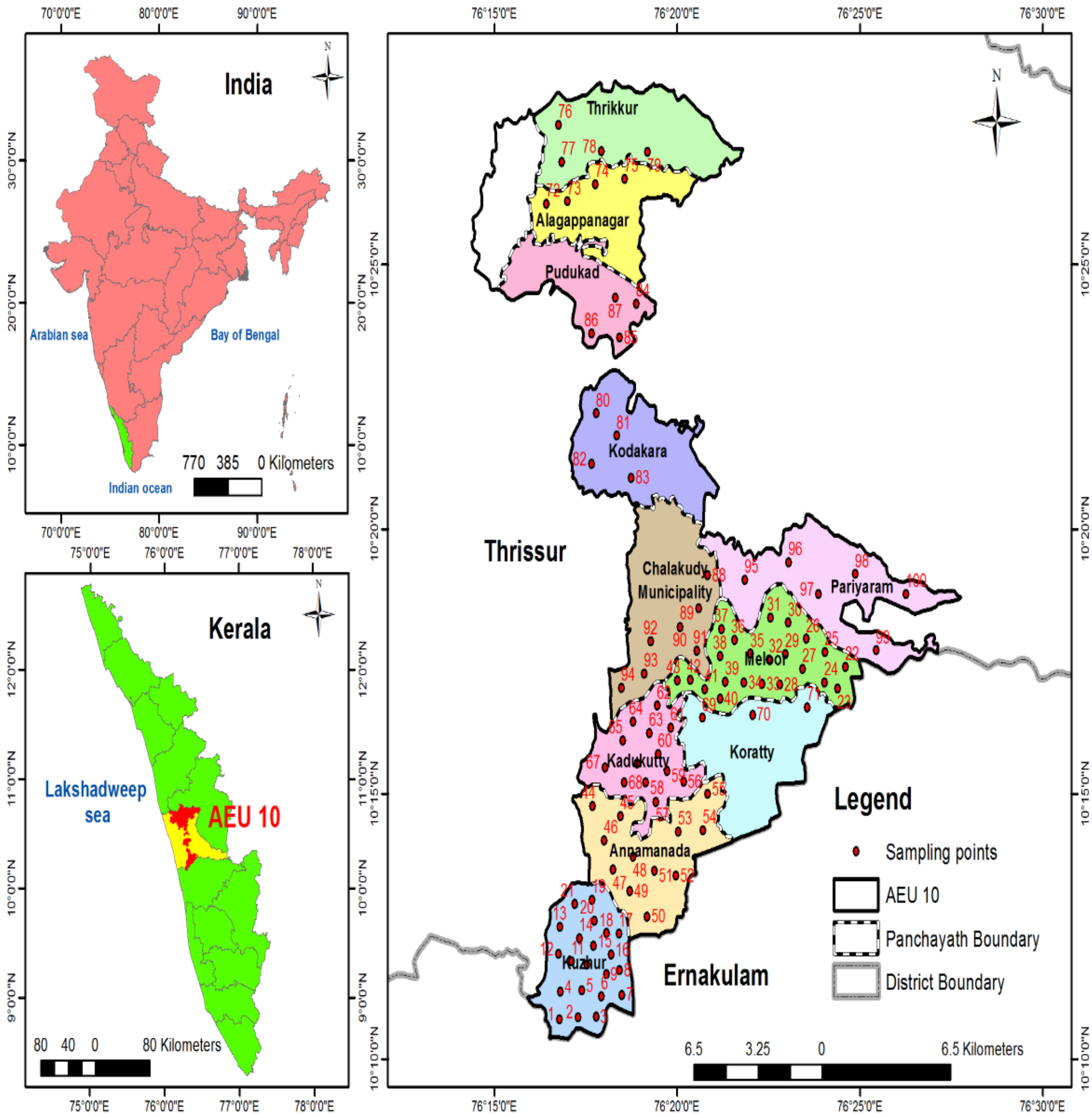


Plate 3.2. Soil slice from ‘V’ shaped cut

Plate 3.3. Collection of soil sample

Plate 3.4. Estimation of soil physical constants

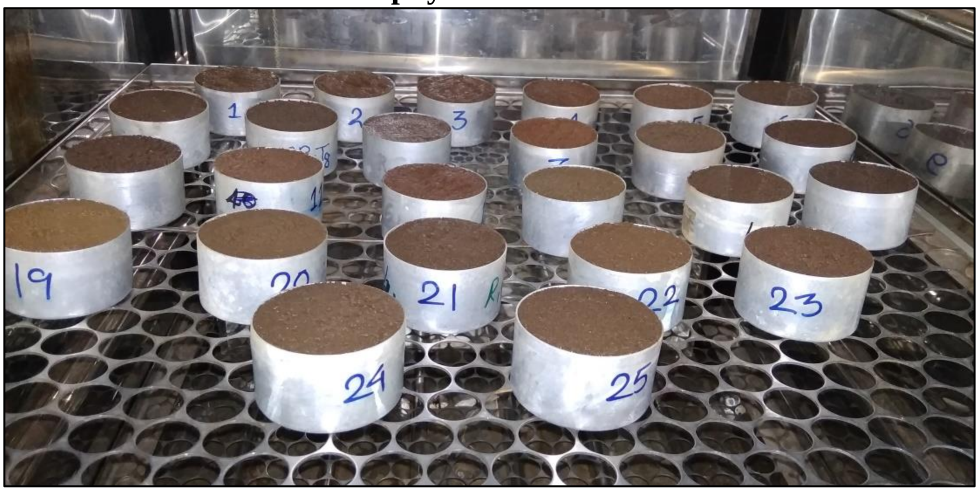


Plate 3.5. Estimation of aggregate stability of soil in Yoders apparatus

Plate 3.6. Estimation of available phosphorus

Plate 3.7. Estimation of available micro nutrients

Plate 3.8. Estimation of hot water soluble boron

Plate 3.9. Analysis of organic carbon

Plate 3.10. Analysis of Microbial Biomass Carbon

Results

4. RESULTS

The results obtained from the study of soil quality parameters in the flood affected areas of AEU 10 in Thrissur District are presented in this chapter.

4.1. Physical attributes

The analytical data on the physical properties of soil samples studied are presented in Table 4.1 and the summary statistics of the parameters are presented in Table 4.3.

4.1.1. Bulk density (BD)

The bulk density of the soil samples collected from the flood affected *panchayats* of AEU 10 in Thrissur district ranged from 0.67 Mg m^{-3} to 1.64 Mg m^{-3} with a mean value of 1.24 Mg m^{-3}. The highest bulk density was observed in Kodakara *panchayat* (Sample No. 81) and the lowest in Meloor (Sample No. 42). Samples from Kodakara *panchayat* recorded highest average bulk density of 1.58 Mg m^{-3} and the lowest average density of 1.07 Mg m^{-3} was found in Pariyaram. Significantly lower mean values for bulk density was recorded in Pariyaram, Chalakudy, Thrikkur, Koratty, Kadukutty and Meloor *panchayats*. Eighty two per cent of the samples including all samples of Meloor and Pariyaram had a bulk density below 1.40 Mg m^{-3}.

4.1.2. Particle density (PD)

The Particle density of soil samples collected from different *panchayats* are presented in Table 4.1. The highest particle density of 2.40 Mg m^{-3} was recorded in Annamanda (Sample No. 49) and the lowest in sample No. 34 from Meloor *panchayat* (1.75 Mg m^{-3}). The mean particle density of soil was significantly higher in Thrikkur *panchayat* (2.14 Mg m^{-3}).

4.1.3. Soil porosity

The soil porosity in samples collected from different *panchayats* ranged from

34.00 to 52.69 per cent. The highest per cent of pore space was observed in Meloor (Sample No. 40) and the lowest in Kodakara (Sample No. 80). Porosity was medium (30-50%) in ninety six per cent samples and high (>50%) in four per cent samples. Maximum average porosity of 45.62 per cent was noted in Meloor. The lowest mean porosity was recorded as 38.11 per cent in samples from Kodakara which was comparable to soil porosity in Kuzhur, Alagappanagar and Pudukkad *panchayats*.

4.1.4. Maximum water holding capacity (WHC)

The water holding capacity of soil was found to be highest (43.78%) in sample No. 39 of Meloor *panchayat* and the lowest (23.16%) in Kodakara (Sample No. 80). The water holding capacity of all soil samples collected from the flood affected areas were in the medium range (20-50%). About 71 per cent of the samples had WHC between 30-40 per cent. Pariyaram showed the highest average WHC of 36.38 per cent whereas the average water holding capacity of samples from Kodakara (26.48%) was significantly lower than other *panchayats.*

4.1.5. Soil moisture content (SMC)

Soil moisture content in the samples at the time of sample collection is shown in Table 4.1. The lowest moisture content of 10 per cent on gravimetric basis was recorded from Annamanada (Sample No. 54) and the highest (58.16 %) from Chalakudy (Sample No. 93). The mean moisture content in soils from different *panchayats* is depicted in Table 4.4. Soil moisture content in samples from Pariyaram ranged from 15.02 to 38.46 per cent with the highest mean value of 27.31 per cent which was comparable with the mean values in Kadukutty, Koratty, Thrikkur, Pudukad and Chalakudy.

Table 4.1. Physical and electro-chemical properties of soil

Sample No	Moisture (%)	WHC (%)	PD ($Mg\ m^{-3}$)	BD ($Mg\ m^{-3}$)	Porosity (%)	MWD (mm)	pH	EC ($dS\ m^{-1}$)
1	24.36	34.94	2.05	1.09	46.71	1.04	5.56	0.11
2	17.38	34.32	2.09	1.39	43.85	2.06	5.28	0.09
3	13.74	30.68	2.15	1.24	40.81	1.06	5.03	0.06
4	14.21	32.38	2.09	1.45	41.95	1.08	6.55	0.06
5	14.96	34.47	2.04	1.35	43.30	3.54	6.29	0.08
6	13.65	29.98	2.08	1.25	41.81	1.19	5.88	0.07
7	19.77	30.35	2.08	1.37	44.68	1.94	5.44	0.08
8	16.97	34.51	1.95	1.10	43.19	3.04	6.15	0.12
9	14.19	34.29	2.04	1.20	43.28	0.92	6.36	0.89
10	17.46	33.53	2.16	1.41	43.76	2.56	5.67	0.07
11	21.21	35.82	2.07	1.31	44.43	2.64	5.64	0.10
12	20.59	35.93	1.99	1.08	47.28	0.86	6.54	0.13
13	14.20	26.67	2.18	1.37	38.90	0.73	6.28	0.06
14	17.31	32.58	2.04	1.24	41.49	1.76	5.62	0.08
15	14.29	33.08	2.12	1.33	45.04	2.26	5.43	0.11
16	14.70	28.88	2.11	1.11	38.42	0.78	5.58	0.05
17	12.14	25.31	2.15	1.37	36.31	0.71	5.73	0.05
18	16.72	31.59	2.06	1.31	40.33	1.20	4.94	0.06
19	14.98	27.49	2.07	1.30	38.82	1.96	6.09	0.06
20	10.48	25.33	2.24	1.40	36.70	1.01	6.06	0.03
21	15.27	26.18	2.13	1.38	38.65	1.34	5.79	0.06
22	13.67	30.92	2.13	1.10	43.19	1.10	5.00	0.03
23	21.32	32.34	2.12	1.08	46.38	1.46	4.88	0.10
24	24.23	32.50	1.95	0.90	47.13	1.96	5.42	0.14
25	19.54	32.47	2.03	1.20	49.45	3.87	5.07	0.14
26	18.66	31.70	2.07	1.06	46.10	1.93	4.66	0.20
27	15.48	28.74	2.04	1.23	42.11	3.34	4.84	0.03
28	15.63	33.42	1.97	1.02	42.03	2.29	6.39	0.10
29	25.17	32.26	2.06	1.17	46.83	3.22	4.31	0.09
30	18.25	30.39	2.12	1.09	41.22	1.31	4.88	0.08
31	20.06	31.09	2.11	1.23	46.36	1.68	4.52	0.11
32	21.57	29.65	2.13	0.81	44.58	2.17	4.38	0.13
33	11.59	31.70	2.21	1.30	44.09	1.23	4.92	0.72
34	19.19	24.76	1.75	1.08	37.09	4.81	4.09	0.60
35	11.15	30.58	2.13	1.10	40.64	1.69	5.24	0.28
36	17.68	30.89	2.08	1.30	42.56	1.34	6.01	0.07

Sample No	Moisture (%)	WHC (%)	PD (Mg m^{-3})	BD (Mg m^{-3})	Porosity (%)	MWD (mm)	pH	EC (dS m^{-1})
37	23.75	33.98	2.00	1.19	49.68	0.81	4.52	0.11
38	26.09	39.97	1.91	1.10	52.00	2.26	5.32	0.09
39	25.81	43.78	1.87	1.23	49.31	1.51	6.34	0.07
40	14.48	43.17	2.01	1.18	52.69	1.51	5.07	0.11
41	17.32	33.38	2.01	1.21	47.81	0.95	5.56	0.07
42	15.76	29.48	2.03	0.67	44.81	1.03	6.09	0.03
43	20.71	33.40	2.04	1.23	47.68	1.38	5.28	0.05
44	21.07	34.41	2.08	1.19	44.81	2.08	6.06	0.45
45	20.31	39.91	1.87	1.04	47.52	5.04	5.61	0.22
46	16.77	32.84	2.13	1.30	43.69	1.41	5.36	0.09
47	21.30	33.93	2.04	1.34	43.27	3.01	5.76	0.16
48	18.50	30.67	2.06	1.48	42.11	1.19	6.01	0.08
49	23.58	32.31	2.40	1.26	52.05	1.98	5.52	0.12
50	22.54	34.30	2.13	1.13	45.20	0.81	4.67	0.10
51	19.34	28.54	2.07	1.44	39.77	1.47	5.90	0.08
52	22.77	28.26	2.13	1.29	42.88	1.28	4.69	0.10
53	13.91	32.66	2.17	1.51	38.90	1.42	6.39	0.10
54	10.00	34.45	2.10	1.51	39.02	2.08	5.49	0.15
55	24.31	34.32	2.13	1.14	42.88	1.66	5.57	0.12
56	14.79	27.53	2.14	1.45	38.79	2.54	5.64	0.06
57	14.29	29.25	2.10	1.39	41.33	2.13	5.28	0.04
58	21.01	29.43	2.10	1.42	40.18	1.14	5.94	0.07
59	22.78	34.35	1.99	1.03	49.70	3.07	4.13	0.11
60	30.63	33.49	2.10	1.13	45.58	1.90	4.80	0.18
61	16.53	29.35	2.14	1.44	42.82	3.15	5.30	0.14
62	15.31	34.47	1.97	1.27	45.59	1.92	5.83	0.23
63	25.35	32.38	2.11	1.13	44.04	1.40	5.70	0.20
64	23.31	31.78	2.14	1.29	45.58	2.17	5.03	0.10
65	19.64	37.43	2.17	1.31	42.72	1.05	5.18	0.10
66	25.57	30.42	1.97	1.23	44.43	1.31	4.68	0.08
67	27.39	38.31	2.00	0.91	50.61	5.39	4.67	0.24
68	21.13	35.62	2.08	1.41	44.81	0.67	4.96	0.08
69	17.93	33.33	2.04	1.15	46.18	3.32	5.31	0.24
70	22.77	32.73	1.97	1.14	44.43	1.08	4.97	0.08
71	23.38	32.68	2.01	1.29	44.63	1.89	4.89	0.08
72	18.02	34.19	2.00	1.37	44.04	1.93	6.30	0.04
73	14.21	34.80	2.05	1.45	43.31	1.80	6.52	0.03

Sample No	Moisture (%)	WHC (%)	PD (Mg m^{-3})	BD (Mg m^{-3})	Porosity (%)	MWD (mm)	pH	EC (dS m^{-1})
74	16.97	33.26	2.03	1.31	41.96	1.65	6.60	0.04
75	17.22	29.02	2.16	1.43	39.40	0.63	6.53	0.05
76	20.13	30.00	2.13	1.18	40.98	1.33	5.94	0.04
77	23.35	32.19	2.16	1.33	43.27	1.13	6.65	0.04
78	17.03	29.66	2.23	1.28	40.81	2.30	6.65	0.03
79	20.00	37.10	2.04	1.11	45.58	2.63	6.48	0.03
80	15.28	23.16	2.16	1.53	34.00	1.55	5.05	0.04
81	13.35	24.37	2.19	1.58	36.16	1.48	6.21	0.06
82	16.91	28.30	2.05	1.64	42.49	1.72	6.39	0.04
83	15.31	30.10	2.08	1.56	39.79	1.10	6.27	0.08
84	22.55	33.31	1.92	1.21	45.39	1.54	5.75	0.06
85	27.87	35.42	1.96	1.14	43.27	2.31	7.00	0.18
86	14.32	28.32	2.19	1.50	39.65	2.52	6.24	0.09
87	22.06	32.71	2.06	1.35	41.63	1.02	6.04	0.18
88	22.22	35.64	2.15	1.25	49.06	1.00	6.08	0.29
89	13.24	28.57	2.17	1.47	40.18	1.53	5.73	0.05
90	14.07	26.48	2.15	1.33	38.14	1.05	5.68	0.09
91	25.27	30.82	2.11	1.10	40.18	2.48	4.90	0.10
92	18.62	30.40	2.13	1.39	42.49	1.17	5.22	0.07
93	58.16	39.75	2.09	0.78	48.67	5.35	5.50	0.19
94	22.90	34.21	2.04	1.37	44.61	1.05	6.28	0.09
95	15.02	38.32	2.00	1.24	44.81	2.24	4.77	0.08
96	27.86	42.52	1.87	1.04	47.68	4.58	5.12	0.14
97	24.46	29.91	2.07	1.10	39.79	1.57	5.11	0.19
98	27.15	30.98	1.93	1.15	39.17	1.80	6.05	0.13
99	30.91	37.54	2.01	0.87	47.68	1.57	5.48	0.12
100	38.46	38.98	2.13	1.03	49.06	1.56	5.42	0.18

Table 4.2. Chemical and biological properties of soil

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
1	423.36	457.82	303.07	869.00	135.25	84.12	81.06	43.11	4.17	11.90	0.30	0.07	1.55	59.44	432.61
2	254.02	139.51	413.73	598.25	93.25	90.02	52.01	25.32	2.85	2.44	0.27	0.13	0.93	535.00	374.33
3	254.02	167.02	121.41	320.00	52.25	71.93	68.65	13.06	3.37	2.31	0.34	0.07	1.13	6.79	487.19
4	211.68	290.81	296.58	777.75	79.50	78.62	60.43	33.44	5.65	9.05	0.23	0.07	1.13	20.04	51.57
5	211.68	202.39	203.73	1036.00	98.75	64.47	81.91	69.30	12.45	7.34	0.22	0.03	1.49	11.21	78.02
6	254.02	272.14	192.08	611.75	80.50	84.91	87.88	51.88	5.65	9.75	0.17	0.07	1.10	4.42	76.85
7	275.18	509.89	388.19	686.25	70.50	67.22	86.86	49.57	5.13	2.93	0.39	0.03	1.02	28.19	302.03
8	402.19	144.42	229.71	1055.00	155.00	53.07	73.99	51.45	4.15	6.63	0.62	0.03	1.78	31.93	345.98
9	232.85	240.70	322.11	1137.00	141.25	95.91	89.31	43.27	4.48	5.35	0.39	0.07	0.79	20.04	77.33
10	169.34	142.46	196.34	561.75	82.25	48.74	83.44	30.28	2.82	4.09	0.52	0.07	0.72	186.83	133.82
11	275.18	92.35	107.63	714.25	138.75	85.65	90.23	31.20	4.29	3.67	0.20	0.07	1.19	22.76	167.35
12	338.69	331.09	830.82	1868.50	275.25	96.30	76.27	44.60	4.77	9.98	0.63	0.03	1.58	22.42	277.04
13	296.35	244.63	210.67	1049.25	177.50	100.93	83.46	20.18	5.77	5.00	0.18	0.03	0.72	14.61	206.25
14	296.35	372.35	277.09	917.00	76.50	106.48	83.17	23.60	4.68	6.43	0.25	0.07	1.33	26.50	267.16
15	296.35	440.14	163.07	1026.50	103.50	67.59	63.61	25.90	7.73	21.57	0.22	0.03	1.47	3.40	206.45

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
16	211.68	273.12	238.78	685.50	87.75	77.31	67.40	23.10	3.78	7.86	0.27	0.07	0.72	1.02	51.86
17	254.02	149.33	170.24	549.50	55.25	73.15	60.11	13.70	4.12	5.27	0.21	0.13	0.63	7.13	150.96
18	296.35	316.35	203.50	547.50	69.75	74.54	56.12	18.20	3.81	2.60	0.17	0.10	0.63	2.04	185.77
19	211.68	270.18	173.60	911.75	120.50	72.22	79.27	19.60	4.44	9.22	0.19	0.07	1.15	27.17	234.15
20	127.01	327.16	119.84	619.50	34.75	78.24	73.88	14.66	4.28	5.00	0.13	0.07	0.40	7.47	246.61
21	254.02	523.65	302.51	921.00	88.00	85.65	73.62	29.38	6.53	6.58	0.18	0.17	0.86	2.72	26.10
22	84.67	139.51	302.51	465.25	74.50	75.46	43.60	14.76	3.98	7.25	0.22	0.03	1.84	13.60	208.86
23	101.61	259.37	429.86	277.75	47.00	69.91	53.10	8.79	4.64	2.20	0.24	0.40	1.34	14.94	408.40
24	93.14	423.44	473.20	967.75	137.50	76.85	56.27	58.23	4.90	6.82	0.24	0.03	1.75	20.29	186.17
25	169.34	187.65	398.83	608.75	67.75	104.17	59.15	9.58	4.00	4.00	0.39	0.07	2.13	11.37	391.71
26	211.68	333.05	346.98	493.00	71.00	95.83	25.66	36.94	3.09	5.98	0.34	0.20	1.63	16.27	51.24
27	135.48	187.65	94.64	339.50	25.00	70.83	76.63	16.97	3.43	1.73	0.16	0.07	0.76	13.15	27.93
28	127.01	290.81	386.62	1281.25	173.50	71.30	53.41	55.54	4.04	6.27	0.25	0.07	1.98	93.18	432.00
29	84.67	154.25	252.34	362.75	23.00	76.39	60.59	7.52	3.28	2.24	0.19	0.20	1.36	9.59	27.39
30	160.88	124.77	172.03	387.75	47.25	93.06	74.30	9.33	3.95	1.87	0.30	0.20	1.32	10.70	135.61
31	135.48	166.04	2836.29	392.50	33.00	74.07	54.93	7.99	3.70	1.80	0.16	0.13	1.30	6.24	314.01

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} $24h^{-1}$)	(µg g^{-1})
32	169.34	179.79	199.70	233.75	32.00	57.87	74.56	4.96	4.10	2.61	0.21	0.67	1.47	17.61	131.05
33	169.34	769.26	316.51	309.25	74.75	108.33	76.19	15.51	4.28	8.51	0.37	0.20	0.89	12.26	436.25
34	135.48	625.82	668.30	415.50	75.25	123.61	79.15	12.56	3.22	6.83	0.28	0.33	1.63	10.03	243.00
35	338.69	307.51	535.14	517.50	132.00	123.15	75.10	35.76	3.43	6.57	0.24	0.13	1.32	40.35	110.19
36	152.41	262.32	326.37	836.00	130.50	87.04	77.71	51.94	5.01	4.68	0.14	0.07	1.28	40.57	363.99
37	118.54	629.75	451.58	403.25	64.25	94.91	70.14	44.11	4.51	4.69	0.19	0.53	0.95	10.25	24.99
38	101.61	146.39	452.48	680.00	120.50	65.28	44.48	18.59	3.83	3.02	0.24	0.07	1.71	18.73	27.28
39	338.69	851.79	2229.47	1824.75	345.00	149.54	88.58	81.91	5.42	6.81	0.73	0.13	2.83	91.62	49.73
40	67.74	121.82	423.70	564.75	101.50	102.78	86.20	24.24	3.40	3.57	0.47	0.20	1.49	9.14	429.27
41	118.54	145.40	328.61	668.25	123.00	96.76	44.24	49.83	5.05	3.76	1.47	0.10	1.40	32.55	257.89
42	101.61	208.28	486.42	626.75	139.00	115.28	40.93	27.35	4.53	4.24	1.71	0.07	1.13	30.54	176.16
43	101.61	94.32	183.57	456.00	103.50	99.07	14.72	9.70	2.34	2.35	0.01	0.07	0.74	9.36	175.65
44	338.69	207.00	339.58	1093.25	128.00	117.13	94.42	40.08	15.19	7.97	0.36	0.07	1.99	36.56	206.92
45	719.71	308.00	554.29	1897.75	321.75	100.46	56.26	75.00	4.69	16.07	0.58	0.03	3.75	81.36	53.44
46	275.18	132.00	206.53	653.00	79.75	88.43	76.48	13.00	3.29	4.85	0.10	0.03	0.88	24.52	793.19
47	338.69	88.00	365.23	1014.50	119.75	94.91	67.15	33.91	4.37	6.47	0.10	0.07	1.72	16.27	471.60

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
48	338.69	116.00	211.01	697.00	76.25	85.65	77.31	18.15	4.15	3.86	0.20	0.03	0.73	41.91	349.75
49	338.69	105.00	358.85	961.00	144.00	93.98	81.48	31.85	5.20	7.17	0.22	0.03	1.38	14.49	85.04
50	254.02	78.00	236.54	670.50	67.25	118.52	66.96	20.12	4.39	6.11	0.29	0.13	0.92	12.48	314.00
51	381.02	257.00	343.62	1367.50	96.00	93.06	77.52	34.30	8.59	6.82	0.12	0.03	1.30	42.80	167.09
52	254.02	171.00	302.96	636.75	60.00	98.61	77.84	20.85	5.39	6.81	0.28	0.17	1.03	11.15	55.24
53	296.35	136.00	353.14	1196.25	80.25	85.19	146.80	54.42	3.19	4.51	0.20	0.03	0.92	75.57	159.32
54	296.35	464.00	311.14	853.50	107.25	92.13	187.10	65.82	5.07	11.85	0.24	0.07	1.38	17.61	865.48
55	275.18	178.00	341.15	685.25	86.75	131.48	160.60	41.89	2.07	7.12	0.22	0.07	1.01	25.19	27.07
56	296.35	118.00	354.37	666.50	66.25	81.02	60.17	50.03	4.73	2.72	1.09	0.07	0.82	16.50	228.85
57	338.69	66.00	156.13	542.75	71.00	93.52	36.26	65.38	2.94	2.32	1.45	0.07	0.85	10.92	565.80
58	359.86	103.00	322.67	942.00	125.25	91.67	141.18	34.10	4.65	4.26	0.58	0.03	1.32	38.56	273.27
59	571.54	157.00	376.54	274.25	187.50	74.07	51.02	3.18	4.09	0.95	1.75	1.27	1.92	9.59	311.97
60	423.36	348.00	914.70	732.25	82.00	99.54	189.20	51.15	4.74	4.94	1.49	0.13	1.67	20.73	25.69
61	423.36	347.00	335.33	875.75	127.50	82.41	179.40	50.85	12.04	12.49	1.62	0.03	1.35	9.14	367.74
62	508.03	333.00	320.66	1304.50	190.75	80.56	153.70	82.00	15.01	11.79	1.31	0.07	1.35	68.09	403.52
63	296.35	573.00	515.54	1065.00	109.75	88.89	128.06	62.72	3.27	8.46	0.29	0.07	0.82	44.99	233.64

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
64	359.86	283.00	224.34	632.00	57.50	100.00	120.29	4.84	3.94	1.28	1.31	0.03	1.07	44.99	335.48
65	338.69	308.00	772.69	1012.25	105.50	126.85	144.88	60.86	3.26	4.20	1.91	0.03	0.64	29.59	306.14
66	465.70	411.00	344.96	692.75	76.50	85.19	111.52	29.18	3.16	4.54	1.45	0.20	1.03	20.27	538.91
67	338.69	189.00	354.93	912.75	71.75	101.39	203.46	12.81	3.75	1.71	1.16	0.10	1.85	31.21	61.46
68	338.69	48.00	210.00	726.75	77.00	67.13	118.31	52.33	3.46	2.15	0.28	0.03	0.73	24.32	158.89
69	423.36	69.00	431.54	1354.75	165.00	81.48	109.60	77.20	3.36	7.36	0.56	0.03	2.57	32.83	104.46
70	465.70	232.00	258.16	854.75	66.75	110.19	59.21	13.99	3.97	3.73	0.44	0.07	1.23	17.83	349.66
71	275.18	77.00	263.31	620.25	70.75	92.13	33.11	22.11	2.76	2.77	0.36	0.03	0.87	15.00	28.52
72	381.02	120.45	451.36	1584.00	202.50	74.34	447.00	129.50	8.22	10.90	0.01	0.07	2.03	12.32	219.34
73	254.02	147.92	346.64	1163.25	147.50	76.00	55.00	56.57	3.27	4.02	0.02	0.03	0.98	55.93	1022.10
74	254.02	191.25	407.34	1308.50	136.00	111.30	114.80	92.80	16.82	55.12	0.09	0.03	1.51	72.14	208.27
75	211.68	113.06	534.58	1328.75	128.50	96.35	207.99	69.58	5.50	9.96	0.03	0.03	0.73	47.83	585.19
76	296.35	214.49	335.66	1110.50	100.50	97.59	75.30	77.20	6.85	6.44	1.22	0.07	1.38	30.23	107.73
77	338.69	147.92	547.01	1486.00	140.25	71.01	202.73	52.46	6.66	8.17	1.79	0.03	1.15	58.43	206.26
78	338.69	178.57	261.07	1076.50	105.75	88.87	88.04	57.57	34.50	38.34	0.05	0.03	1.41	21.74	26.61
79	338.69	88.75	237.10	1416.00	92.75	83.06	83.00	75.60	3.49	11.02	0.39	0.07	1.64	58.09	80.07

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
80	254.02	119.40	105.39	318.75	38.50	90.95	105.65	17.92	2.07	1.99	0.09	0.07	0.55	14.19	413.51
81	254.02	318.04	310.91	973.25	128.00	74.75	167.86	78.71	4.66	7.03	0.12	0.03	0.76	36.48	171.22
82	254.02	139.47	287.62	921.50	119.25	76.83	206.64	80.24	4.61	6.92	0.01	0.03	0.76	32.42	266.32
83	296.35	234.57	302.18	1182.25	108.75	67.28	184.15	86.50	4.74	8.92	0.17	0.07	0.93	65.25	385.38
84	232.85	215.55	213.14	892.00	87.00	61.05	115.67	34.35	4.28	3.82	0.01	0.07	0.99	57.15	141.47
85	423.36	549.43	508.48	2232.00	113.50	100.50	105.02	120.29	6.72	35.99	0.15	0.07	2.24	123.21	149.49
86	296.35	383.55	717.47	939.25	232.75	71.01	155.18	81.94	11.55	21.04	0.26	0.07	1.07	39.72	232.36
87	402.19	289.51	434.00	1764.00	86.25	80.15	162.29	126.63	7.18	28.53	0.27	0.03	1.99	74.58	450.35
88	338.69	375.09	502.66	1143.00	87.50	64.37	126.80	39.11	4.72	7.83	0.22	0.07	1.09	67.28	182.18
89	296.35	147.92	198.58	523.00	69.00	72.67	20.13	14.05	2.61	2.20	0.22	0.03	0.89	26.34	119.58
90	296.35	183.85	443.74	544.00	62.25	73.92	63.29	21.40	2.97	5.50	0.41	0.07	0.89	27.56	317.57
91	254.02	139.47	162.51	464.50	67.00	75.17	66.75	22.61	3.35	2.82	0.16	0.10	0.80	17.43	267.11
92	254.02	360.30	378.67	663.00	100.50	49.00	157.36	24.49	3.33	3.79	0.30	0.03	0.58	33.64	215.68
93	381.02	172.23	343.50	1153.25	124.25	88.46	116.88	78.57	4.00	9.81	0.38	0.03	2.17	52.28	198.51
94	296.35	123.62	123.87	985.75	206.25	105.07	250.74	37.14	2.18	4.94	0.16	0.07	0.50	34.05	28.20
95	84.67	132.08	439.04	450.25	118.50	92.61	80.47	16.30	2.50	1.73	0.21	0.47	1.64	17.02	203.94

Sample No	Available nutrient status											Ex. acidity	OC	DHA	MBC
	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B				
	(kg ha^{-1})			(mg kg^{-1})								(cmol kg^{-1})	(%)	(µg TPF g^{-1} 24h^{-1})	(µg g^{-1})
96	84.67	95.09	221.42	898.25	50.00	84.30	80.36	29.04	3.18	3.94	0.09	0.10	2.58	20.67	257.42
97	254.02	181.74	442.62	649.25	98.75	67.28	31.50	46.14	1.52	2.82	0.29	0.07	1.76	21.48	494.93
98	275.18	189.13	366.35	1255.25	89.75	76.41	71.30	55.04	2.99	8.32	0.18	0.07	2.16	63.23	189.79
99	402.19	135.25	518.00	879.75	145.00	85.96	58.38	34.98	3.22	2.60	0.27	0.03	1.85	34.05	234.10
100	232.85	112.00	1167.26	659.00	118.00	90.12	132.50	43.41	1.99	3.03	0.25	0.07	1.45	44.58	397.59

Table 4.3 Summary statistics of soil properties studied

Character	N	Minimum	Maximum	Mean	Standard Deviation	Std. Error
BD($Mg\ m^{-3}$)	100	0.67	1.64	1.24	0.18	0.16
PD ($Mg\ m^{-3}$)	100	1.75	2.40	2.07	0.09	0.06
Porosity (%)	100	34.00	52.69	43.50	3.75	0.57
Max WHC (%)	100	23.16	43.78	32.38	3.92	0.69
Moisture (%)	100	10.00	58.16	19.65	6.34	1.43
MWD (mm)	100	0.63	5.39	1.88	1.01	0.74
pH	100	4.09	7.00	5.56	0.65	0.28
EC ($dS\ m^{-1}$)	100	0.03	0.89	0.12	0.13	0.37
Av. N ($kg\ ha^{-1}$)	100	67.74	719.71	273.70	114.04	6.89
Av. P ($kg\ ha^{-1}$)	100	48.00	851.79	242.18	153.61	9.87
Av. K ($kg\ ha^{-1}$)	100	94.64	2836.29	391.48	355.52	17.97
Av. Ca ($mg\ kg^{-1}$)	100	233.75	2232.00	854.75	393.27	13.45
Av. Mg ($mg\ kg^{-1}$)	100	23.00	345.00	106.79	55.20	5.34
Av. S ($mg\ kg^{-1}$)	100	48.74	149.54	86.91	17.82	1.91
Av. Fe ($mg\ kg^{-1}$)	100	14.72	447.00	96.44	59.08	6.02
Av. Mn ($mg\ kg^{-1}$)	100	3.18	129.50	40.99	27.23	4.25
Av. Cu ($mg\ kg^{-1}$)	100	1.52	34.50	5.07	4.00	1.78
Av. Zn ($mg\ kg^{-1}$)	100	0.95	55.12	7.26	7.82	2.90
Av. B ($mg\ kg^{-1}$)	100	0.01	1.91	0.59	1.41	1.83
Ex. acidity ($cmol\ kg^{-1}$)	100	0.03	1.27	0.11	0.16	0.48
Organic carbon (%)	100	0.40	3.75	1.30	0.56	0.49
DHA (μg TPF g^{-1} 24 h^{-1})	100	1.02	535.00	36.67	57.49	9.49
MBC ($\mu g\ g^{-1}$)	100	24.99	1022.10	256.03	232.97	14.56

Table 4.4. Variation in physical and electro-chemical properties of soil in different *panchayats*

Panchayat	BD	PD	Porosity	WHC	Moisture content	MWD	pH	EC
	(Mg m^{-3})		(%)			(mm)		dS m^{-1}
Kuzhur	1.29^{bc}	2.09^{ab}	41.89^{ab}	31.35^{a}	16.12^{c}	1.60^{a}	5.8^{bcde}	0.12^{a}
Meloor	1.11^{cd}	2.04^{ab}	45.62^{a}	32.75^{a}	18.96^{bc}	1.95^{a}	5.1^{ef}	0.15^{a}
Annamanada	1.30^{bc}	2.11^{ab}	43.51^{a}	33.05^{a}	19.53^{bc}	1.95^{a}	5.6^{cdef}	0.15^{a}
Kadukutty	1.26^{bcd}	2.08^{ab}	44.32^{a}	32.60^{a}	21.36^{abc}	2.14^{a}	5.2^{ef}	0.12^{a}
Koratty	1.19^{bcd}	2.01^{b}	45.08^{a}	32.91^{a}	21.35^{abc}	2.10^{a}	5.1^{f}	0.13^{a}
Alagappanagar	1.39^{b}	2.06^{ab}	42.18^{ab}	32.82^{a}	16.61^{c}	1.50^{a}	6.5^{a}	0.04^{a}
Thrikkur	1.23^{bcd}	2.14^{a}	42.66^{a}	32.24^{a}	20.13^{abc}	1.85^{a}	6.4^{ab}	0.04^{a}
Kodakara	1.58^{a}	2.12^{ab}	38.11^{b}	26.48^{b}	15.21^{c}	1.46^{a}	6.0^{abcd}	0.06^{a}
Pudukad	1.30^{bc}	2.03^{ab}	42.48^{ab}	32.44^{a}	21.7^{abc}	1.85^{a}	6.3^{abc}	0.13^{a}
Chalakudy	1.24^{bcd}	2.12^{ab}	43.33^{a}	32.27^{a}	24.93^{ab}	1.95^{a}	5.6^{cdef}	0.12^{a}
Pariyaram	1.07^{d}	2.00^{b}	44.70^{a}	36.38^{a}	27.31^{a}	2.22^{a}	5.3^{def}	0.14^{a}
Mean values with common superscripts do not differ significantly								

4.1.6. Aggregate stability

The aggregate stability of soil expressed in terms of Mean Weight Diameter (MWD) of water stable aggregates is represented in Table 4.1. The aggregate stability ranged from 5.39 mm in Kadukutty (Sample No. 67) to 0.63 mm in Alagappanagar (Sample No. 75) with a mean value of 1.88 mm. The MWD of 68 per cent of the samples was found less than 2 mm. Samples from Pariyaram recorded the highest average MWD of 2.22 mm which was statistically comparable to the mean values of all other *panchayats*.

4.2. Electrochemical attributes

4.2.1. Soil pH

Table 4.1 shows the pH of soil samples collected from the flood affected areas. The highest pH of 7.0 was observed in Pudukkad (Sample No. 85) and the lowest in Meloor (Sample No. 34). Ninety two per cent of samples were acidic in reaction with pH below 6.5. Twenty three per cent samples were slightly acidic (6.00-6.50), and twenty two per cent moderately acidic (5.51-6.00). Extreme acidity (3.50-4.50) was recorded in four per cent samples, while nineteen per cent samples were very strongly acidic (4.51-5.00) and twenty four per cent samples strongly acidic (5.01-5.50). The highest mean pH of 6.5 was recorded in Alagappanagar which was comparable to Thrikkur, Kodakara and Pudukkad. The spatial distribution of soil pH classes in different sample locations is shown in Plate 4.1.

4.2.2. Electrical conductivity (EC)

The electrical conductivity of all the samples analysed was less than 1 dS m^{-1}. The electrical conductivity in soil samples ranged from 0.03 dS m^{-1} in Meloor *panchayat* (Sample No. 22) to 0.89 dS m^{-1} in Kuzhur *panchayat* (Sample No. 9). The mean values of electrical conductivity in the soil samples collected from different *panchayats* were not found to vary significantly.

4.3. Chemical attributes

The data on soil chemical properties are shown in Table 4.2.

4.3.1. Available nitrogen (Av. N)

Available nitrogen content in soil samples collected from different flood affected *panchayats* ranged from 67.74 kg ha^{-1} in Meloor (Sample No. 40) to 719.71 kg ha^{-1} in Annamanda (Sample No. 45). Fifty three per cent of samples had low content of Av. N (<280 kg ha^{-1}), while forty five per cent samples were medium (280-560 kg ha^{-1}) and two per cent samples were high in status (>560 kg ha^{-1}). Samples collected from Kadukutty *panchayat* recorded the highest mean value of Av. N (389.17 kg ha^{-1}) which was statistically on par to the status in Koratty, Annamanada, Pudukad, Thrikkur, and Chalakudy. The lowest average value of 146.25 kg ha^{-1} was recorded in Meloor. The spatial distribution of available nitrogen classes in different sample locations is shown in Plate 4.2.

4.3.2. Available phosphorus (Av. P)

Available phosphorus status was found to be very high in all the soil samples and ranged from 48.00 to 851.79 kg ha^{-1}. The lowest content was recorded in Kadukutty (Sample No. 68) and the highest in Meloor (Sample No. 39) with a mean value of 242.18 kg ha^{-1}. The mean values of Av. P were comparatively higher in Pudukad, Chalakudy, Kodakara, Kadukutty, Annamanada, Meloor and Kuzhur.

4.3.3. Available potassium (Av. K)

Available potassium was found to vary widely from 94.64 to 2836.29 kg ha^{-1} in the samples studied. The highest value was recorded in sample number 31 and the lowest in sample number 27 of Meloor *panchayat.* Sixty six per cent samples were high (>275 kg ha^{-1}), thirty one per cent medium (116-275 kg ha^{-1}) and three per cent samples low (<116 kg ha^{-1}) in the status of available potassium. The mean values of available potassium was not found to vary significantly between different *panchayats*. The spatial distribution of available potassium classes in different sample locations is shown in Plate 4.3.

4.3.4. Available calcium (Av. Ca)

Available calcium ranged from 233.75 to 2232.00 mg kg^{-1} soil with a mean value of 854.75 mg kg^{-1}. The lowest content was noted in Meloor (Sample No. 32) and the highest in Pudukkad (Sample No. 85). Ninety seven per cent samples were sufficient with respect to availability of calcium (>300 mg kg^{-1}). Content of available calcium was above 1000 mg kg^{-1} in thirty one per cent samples comprising all samples from Alagappanagar and Thrikkur. The highest average value was observedin Pudukkad (1456.81 mg kg^{-1}) with Alagappanagar and Thrikkur having comparable values.

4.3.5. Available magnesium (Av. Mg)

The available magnesium content in soil samples collected from the flood affected *panchayats* is shown in Table 4.2 and spatial distribution of magnesium classes in Plate 4.4. The highest content of 345 mg kg^{-1} (Sample No. 39) and the lowest of 23 mg kg^{-1} (Sample No. 29) was noted in Meloor *panchayat*. The status of available magnesium was sufficient (>120 mg kg^{-1}) in thirty three per cent of the samples. The highest average content of Av. Mg was in Alagappanagar (153.63 mg kg^{-1}). However the mean values of Av. Mg did not vary significantly between the *panchayats*.

4.3.6. Available sulphur (Av. S)

Available sulphur content in soil samples studied was very high (Table 4.2). It ranged from 48.74 mg kg^{-1} (Sample No. 10) of Kuzhur to 149.54 mg kg^{-1} in Meloor (Sample No. 39), with mean value of 86.91 mg kg^{-1}. Soil samples from Chalakudy had the lowest average content of 75.52 mg kg^{-1} and the highest average value of 99.96 mg kg^{-1} was noted in Annamanada, which was comparable to all other locations.

Table 4.5. Variation in chemical properties of soil in different *panchayats*

Panchayat	**Av. N**	**Av. P**	**Av. K**	**Av. Ca**	**Av. Mg**	**Av. S**	**Av. Fe**	**Av. Mn**	**Av. Cu**	**Av. Zn**	**Av.B**	**Ex acidity**
	(kg ha^{-1})			**(mg kg^{-1})**								**(cmol kg^{-1})**
Kuzhur	264.1^{bc}	281.31^{ab}	260.22^{a}	831.57^{cd}	105.52^{a}	78.91^{ab}	74.89^{cd}	32.13^{c}	5.00^{bc}	6.90^{b}	0.29^{b}	0.07^{a}
Meloor	146.25^{d}	300.41^{ab}	558.87^{a}	596.00^{d}	97.31^{a}	92.34^{ab}	60.44^{d}	27.37^{c}	4.01^{b}c	4.45^{b}	0.39^{b}	0.18^{a}
Annamanada	342.22^{ab}	186.67^{ab}	327.00^{a}	977.19^{bcd}	113.92^{a}	99.96^{a}	97.49^{cd}	37.45^{bc}	5.47^{bc}	7.47^{b}	0.24^{b}	0.06^{a}
Kadukutty	389.17^{a}	252.62^{ab}	400.22^{a}	798.42^{d}	103.71^{a}	90.17^{ab}	125.96^{bcd}	43.03^{bc}	5.31^{bc}	4.75^{b}	1.21^{a}	0.16^{a}
Koratty	388.08^{a}	126.00^{b}	317.67^{a}	943.25^{bcd}	100.83^{a}	94.60^{ab}	67.31^{d}	37.77^{bc}	3.36^{c}	4.62^{b}	0.45^{b}	0.04^{a}
Alagappanagar	275.18^{bc}	143.17^{b}	434.98^{a}	1346.13^{ab}	153.63^{a}	89.49^{ab}	206.20^{a}	87.11^{a}	8.45^{b}	20.00^{a}	0.04^{b}	0.04^{a}
Thrikkur	328.10^{abc}	157.43^{b}	345.21^{a}	1272.25^{abc}	109.81^{a}	85.13^{ab}	112.27^{bcd}	65.71^{ab}	12.88^{a}	15.99^{a}	0.86^{a}	0.05^{a}
Kodakara	264.60^{bc}	202.87^{ab}	251.52^{a}	848.94^{cd}	98.63^{a}	77.45^{ab}	166.08^{ab}	65.84^{ab}	4.02^{bc}	6.22^{b}	0.10^{b}	0.05^{a}
Pudukad	338.69^{ab}	359.51^{a}	468.27^{a}	1456.81^{a}	129.88^{a}	78.18^{ab}	134.54^{bc}	90.80^{a}	7.43^{bc}	22.35^{a}	0.17^{b}	0.06^{a}
Chalakudy	302.40^{abc}	214.64^{ab}	307.65^{a}	782.36^{d}	102.39^{a}	75.52^{b}	114.56^{bcd}	33.91^{c}	3.31^{c}	5.27^{b}	0.26^{b}	0.06^{a}
Pariyaram	222.26^{cd}	140.88^{b}	525.78^{a}	798.63^{d}	103.33^{a}	82.78^{ab}	75.75^{cd}	37.49^{bc}	2.57^{c}	3.74^{b}	0.22^{b}	0.14^{a}
Mean values with common superscripts do not differ significantly												

4.3.7. Available iron (Av. Fe)

Available iron content in the soils studied ranged from 14.72 mg kg^{-1} in Meloor (Sample No. 43) to 447.00 mg kg^{-1} in Alagappanagar (Sample No. 72) with a mean value of 96.44 mg kg^{-1}. None of the samples were deficient (<5mg kg^{-1}) in available iron (Table 4.2). The average content of Av. Fe was significantly higher in Alagappanagar (206.20 mg kg^{-1}) and Kodakara (166.08 mg kg^{-1}) when compared to other *panchayats*.

4.3.8. Available manganese (Av. Mn)

Available manganese content in soil varied from 3.18 to 129.5 mg kg^{-1}. None of the soil samples were deficient (<1 mg kg^{-1}) in available manganese (Table 4.2). The lowest content was recorded in Kadukutty (Sample No. 59) and the highest in Alagappanagar (Sample No. 72). The average content of Av. Mn was significantly higher in Alagappanagar, Thrikkur, Kodakara and Pudukkad *panchayats*.

4.3.9. Available copper (Av. Cu)

The available copper content in the soil samples studied ranged from 1.52 to 34.50 mg kg^{-1}. The lowest content was recorded in Pariyaram (Sample No. 97) and the highest in Thrikkur (Sample No. 78). All the samples collected from the flood affected areas were sufficient (>1 mg kg^{-1}) with respect to the status of Av. Cu. The highest average content of Av. Cu was observed in Thrikkur *panchayat*.

4.3.10. Available zinc (Av. Zn)

Content available zinc varied from 0.95 mg kg^{-1} in Kadukutty (Sample No. 59) to 55.12 mg kg^{-1} in Alagappanagar (Sample No. 74). Deficiency of Av. Zn was observed (<1 mg kg^{-1}) only in one location. The average concentration of Av. Zn was significantly higher in Alagappanagar, Thrikkur, and Pudukkad *panchayats* (Table 4.5)

4.3.11. Available boron (Av. B)

The highest content of available boron (1.91 mg kg^{-1}) was recorded in Kadukutty (Sample No. 65) and the lowest (0.01 mg kg^{-1}) in Meloor (Sample No. 43), Alagappanagar (Sample No. 72), Kodakara (Sample No. 82) and Pudukkad (Sample No. 84). Seventy nine per cent of the samples were deficient with values below 0.50 mg kg^{-1}. The spatial distribution available boron classes in sampling locations is shown in Plate 4.5. The heighest average content of 1.21 mg kg^{-1} was observed in Kadukutty followed by Thrikkur (0.86 mg kg^{-1}) and the lowest average value of 0.04 mg kg^{-1} was in Alagappanagar.

4.3.12. Exchange acidity

The exchange acidity of the samples ranged from 0.03 to 1.27 cmol kg^{-1} with mean value of 0.11 cmol kg^{-1} (Table 4.3). Seventy four per cent of the samples had an exchange acidity below 0.10 cmol kg^{-1} soil. The lowest mean value of 0.04 cmol kg^{-1} was observed in Koratty and Alagappanagar while the highest value of 0.18 cmol kg^{-1} was in Meloor. However, the mean values were not found to vary significantly between the flood affected *panchayats*.

4.4. Biological attributes

The data on biological properties of soil samples are presented in Table 4.2 and the summary statistics are given in Table 4.3**.**

4.4.1. Organic carbon (OC)

Organic carbon content in the soil varied from 0.40 to 3.75 per cent. The highest content of soil organic carbon was detected in Annamanada (Sample No. 45) and the lowest in Kuzhur *panchayat* (Sample No. 20). Twenty nine per cent of the samples were high in organic carbon (>1.50%) and fifty seven per cent had a medium status (0.75-1.5%). Pariyaram had the highest average content of 1.91 per cent soil organic carbon (Table 4.6) whereas, Kodakara recorded the lowest mean value (0.75%). Spatial distribution of organic carbon classes in sampling locations is presented in Plate 4.6.

Table 4.6. Variation in biological properties of soil in different *panchayats*

Panchayat	**OC (%)**	**DHA (µg TPF g^{-1} $24h^{-1}$)**	**MBC (µg g^{-1})**
Kuzhur	1.06^{bc}	49.58^{a}	208.54^{b}
Meloor	1.47^{ab}	24.20^{a}	209.49^{b}
Annamanada	1.42^{abc}	33.33^{a}	295.67^{ab}
Kadukutty	1.19^{bc}	28.38^{a}	293.18^{ab}
Koratty	1.55^{ab}	21.89^{a}	160.88^{b}
Alagappanagar	1.31^{abc}	47.06^{a}	508.72^{a}
Thrikkur	1.40^{abc}	42.12^{a}	105.17^{b}
Kodakara	0.75^{c}	37.09^{a}	309.11^{ab}
Pudukad	1.57^{ab}	73.66^{a}	243.42^{b}
Chalakudy	0.99^{bc}	36.94^{a}	189.83^{b}
Pariyaram	1.91^{a}	33.51^{a}	296.3^{ab}
Mean values with common superscripts do not differ significantly			

4.4.2. Dehydrogenase activity (DHA)

Dehydrogenase enzyme activity in the soil samples studied were found to vary from 1.02 µg TPF g^{-1} $24h^{-1}$ in Sample No. 16 to 532.00 µg TPF g^{-1} $24h^{-1}$ in Sample No. 2 of Kuzhur *panchayat*. The activity was more than 20 µg TPF g^{-1} $24h^{-1}$ in the case of 60 per cent of the samples. However the variation in dehydrogenase activity was not found significant between the locations.

4.4.3. Microbial biomass carbon (MBC)

Microbial biomass carbon was lowest (24.99 µg g^{-1}) in Meloor (Sample No. 37) and highest (1022.10 µg g^{-1}) in Alagappanagar (Sample No. 72). Twenty two per cent samples were very low (<100 µg g^{-1}), forty five per cent low (100-300 µg g^{-1}), sixteen per cent medium (300-400 µg g^{-1}) and seventeen per cent high (>400 µg g^{-1}) in microbial biomass carbon content. Alagappanagar *panchayat* exhibited the highest average content of microbial biomass carbon (508.72 µg g^{-1}) followed by Kodakara, Pariyaram, Annamanada and Kadukutty. The spatial distribution of microbial biomass carbon classes in sampling locations is presented in Plate 4.7.

4.5. Correlation between soil characteristics

The result of correlation analysis is presented in the Table 4.7 and Table 4.8. Significant correlations were found between soil physical properties and organic carbon content in studied soils. The content of organic carbon exhibited significant negative correlation with bulk density (-0.50**) and particle density (-0.54**) and was positively correlated to porosity (0.44**), water holding capacity (0.55**), moisture content (0.37**) and aggregate stability (0.57**) of the soil particles. Bulk density showed a significant negative correlation with porosity (-0.51**) and MWD (-0.31**). Water holding capacity had a strong positive correlation with porosity (0.77**), MWD (0.29**), potassium (0.26**), calcium (0.32**) and magnesium (0.38**) while a negative correlation was observed with bulk density (-0.40**) and particle density (-0.43**).

Organic carbon was also found to have a positive correlation with available potassium (0.29**) and available nitrogen (0.29**). Soil pH was negatively correlated with exchange acidity (-0.50**), and positively correlated with available calcium (0.71**) and magnesium (0.45**). A strong positive correlation of available zinc with copper (0.67**) and manganese (0.56**) was observed. Available magnesium was found to have significant positive correlation with available calcium (0.64**), potassium (0.30**), sulphur (0.23*) and organic carbon (0.46**).

Table 4.7. Correlation analysis of soil physical properties

Soil physical properties	Soil properties	Correlation co-efficient
Bulk Density	Particle density	0.38**
	Porosity	-0.51**
	Moisture content	-0.53**
	Water Holding Capacity	-0.40**
	Aggregate stability	-0.31**
	Soil organic carbon	-0.50**
Particle Density	Porosity	-0.30**
	Moisture content	-0.23**
	Water Holding capacity	-0.43**
	Aggregate stability	-0.38**
	Soil organic carbon	-0.54**
Porosity	Moisture content	0.50**
	Water Holding Capacity	0.77**
	Aggregate stability	0.26**
	Soil organic carbon	0.44**
Moisture content	Water Holding Capacity	0.47**
	Aggregate stability	0.33**
	Soil organic carbon	0.37**
Water Holding Capacity	Aggregate stability	0.29**
	Soil organic carbon	0.55**
Aggregate stability	Soil organic carbon	0.57**

Table 4.8. Pearson correlation for chemical and biological properties of soil

	Av. N	**Av. P**	**Av. K**	**Av. Ca**	**Av. Mg**	**Av. S**	**Av. Mn**	**Av. Cu**	**Exch. acidity**
pH				0.71**	0.45**		0.59**	0.37**	-0.50**
EC		0.34**				0.27**			
OC	0.29**		0.29**	0.46**	0.46**		0.32**		
Av. Ca	0.50**							0.30**	-0.39**
Av. Mg	0.44**	0.20*	0.30**	0.64**					
Av. S		0.24*	0.25*		0.23*				
Av. Fe	0.28**			0.38**	0.24*		0.52**		
Av. Mn	0.37**			0.76**	0.48**			0.33**	-0.31**
Av. Zn	0.25*	0.21*		0.53**	0.25*		0.56**	0.67**	

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

4.6. Nutrient Index (NI)

Nutrient Index of the flood affected area was computed for available nitrogen, phosphorus and potassium.

In the case of available nitrogen, fifty three samples were low (<280 kg ha^{-1}), forty five medium (280-560 kg ha^{-1}) and two samples high in status (>560 kg ha^{-1}). The NI of available N was computed to be 1.49. Available phosphorus content was high in all the samples (>24 kg ha^{-1}) and hence NI was computed as 3.00. The status of available potassium was low in three (<116 kg ha^{-1}), medium in thirty one and high in sixty six samples (>275 kg ha^{-1}). Hence the NI of Av. K was computed as 2.63. The nutrient index of the flood affected areas of AEU 10 in Thrissur district was low (<1.67) with respect to available nitrogen, and high (>2.33) with respect to available phosphorus and potassium.

4.7. Soil quality Index (SQI)

The analytical results of soil quality attributes were quantified to compute Soil Quality Index.

4.7.1. Principal Component Analysis (PCA)

Minimum Data Set (MDS) was formulated through Principal Component Analysis of soil parameters namely moisture content, maximum WHC, particle density (PD), bulk density (BD), porosity, aggregate stability (MWD), soil pH, electrical conductivity (EC). available N, available P, available K, available Ca, available Mg, available S, available Fe, available Mn, available Cu, available Zn, available B, exchangeable acidity, organic carbon (OC), dehydrogenase activity (DHA), and microbial biomass carbon (MBC).

Six principal components (PCs) had eigenvalue >1, explaining variance of >5 per cent and were selected for further analysis. The PCs exhibited a variance of 20.40, 17.20, 7.20, 6.60, 5.90 and 5.10 per cent respectively (Table 4.9).

Table 4.9. Principal components with factor loading of soil parameters

Parameters	**PC 1**	**PC 2**	**PC 3**	**PC 4**	**PC 5**	**PC 6**
Eigenvalues	4.692	3.956	1.655	1.509	1.358	1.163
% variance	20.40	17.20	7.20	6.60	5.90	5.10
Cumulative %	20.40	37.60	44.80	51.40	57.30	62.30
Factor loading						
Moisture content	0.190	-0.248	-0.229	0.021	0.050	0.257
Max WHC	0.285	-0.234	-0.201	0.128	-0.180	0.092
PD	-0.213	0.214	0.004	0.072	0.168	0.379
BD	-0.122	**0.367**	0.003	0.182	0.008	-0.131
Porosity	0.189	-0.328	-0.145	0.083	-0.052	0.250
MWD	0.162	-0.211	-0.161	-0.305	0.226	-0.328
OC	0.341	-0.192	-0.059	-0.182	0.007	-0.179
Av. N	0.238	0.089	-0.001	0.191	**0.480**	-0.125
Av.P	0.114	0.005	**0.571**	-0.002	-0.147	-0.111
Av.K	0.167	-0.097	0.243	0.261	-0.249	0.235
Av.Ca	**0.381**	0.210	-0.061	0.036	-0.078	-0.020
Av.Mg	0.340	0.063	0.072	0.183	-0.034	-0.032
Av.S	0.137	-0.081	0.404	0.125	-0.073	0.228
Av.Fe	0.150	0.200	-0.072	0.221	0.220	0.096
Av.Mn	0.319	0.251	-0.060	0.031	0.022	-0.039
Av.Cu	0.148	0.216	0.125	**-0.412**	0.243	0.184
Av.Zn	0.233	0.239	0.112	**-0.392**	0.046	0.055
Av.B	0.078	-0.101	0.138	0.352	**0.526**	0.093
Ex. acidity	-0.067	-0.257	0.191	-0.022	0.276	-0.133
DHA	0.099	0.054	-0.163	0.167	-0.223	-0.245
MBC	-0.044	0.070	-0.029	0.351	-0.018	**-0.486**
pH	0.192	**0.370**	-0.107	-0.009	-0.198	0.062
EC	0.087	-0.117	0.411	-0.089	-0.064	-0.231

4.7.2. Minimum data set (MDS)

Parameters with highly weighed factor loadings (absolute values within 10 per cent of the highest factor loading) from each PC (Table 4.9) were taken for preparation of MDS (Andrews *et al.*, 2002). From the first PC, available calcium with highest factor loading was retained in the MDS. Bulk density and pH were retained in the second PC and available phosphorus in the third PC. Available copper and zinc were highly weighted variables in the fourth PC but as they were significantly correlated (0.67^{**}); available copper (highest loading in the PC) was selected for MDS. In the same way, available nitrogen and boron were retained in the fifth PC and, microbial biomass carbon in the sixth PC. Thus, eight parameters were retained in the MDS (Table 4.10).

Table 4.10. Minimum data set (MDS) of soil quality parameters

PC1	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Av. Ca	pH	Av. P	Av. Cu	Av. B	MBC
	BD			Av. N	

4.7.3. Scoring of MDS indicators

The selected variables were scored using non-linear and linear scoring functions where, the variables were transformed into numerical scores ranging from 0 – 1. Three types of ranking was used namely, ‘more is better’, ‘less is better’, and ‘optimum is better’ depending on the contribution of the variable to soil quality (Table 4.11). Fig. 4.1 illustrates the scoring functions of different MDS indicators.

I. More is better

Soil pH, Av. N and MBC were scored following ‘more is better’ function as the increase in values of these parameters are considered good in terms of soil function within the range studied.

II. Less is better

Bulk density was included under 'less is better' function as increase in BD restricts root penetration and plant growth. Available copper was also included in this function because all the soil samples studied were sufficient in status.

III. Optimum is better

Soil parameters like available calcium, phosphorus and boron are best within the optimum range, beyond which it may have adverse effect on soil quality. Hence they were scored as 'more is better' up to a threshold value and 'less is better' beyond it.

Table 4.11. Scoring function of MDS indicators

More is better	Less is better	Optimum curve (threshold value)
pH,	BD	Av. Ca (1000 mg kg^{-1})
Av. N	Av. Cu	Av. P (100 kg ha^{-1})
MBC		Av. B (1.1 mg kg^{-1})

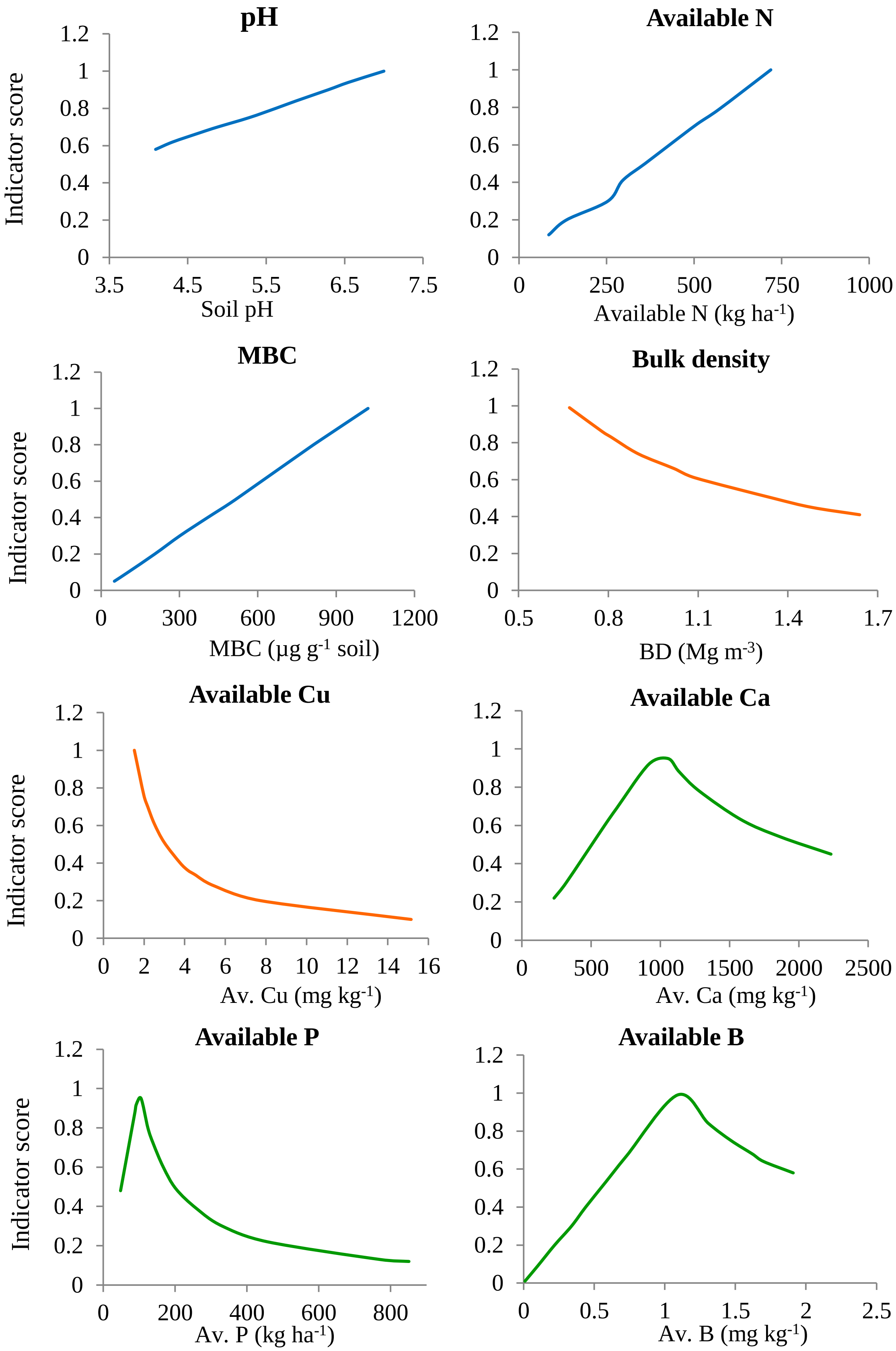
4.7.4. Weighing factor (W_i)

The amount of variance in each PC was divided by the maximum cumulative variance of all PCs to obtain the weighing factor (Table 4.12).

Table 4.12. Weighing factors of principal component

PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
0.33	0.28	0.12	0.11	0.09	0.08

Fig 4.1. Scoring of MDS parameters



4.7.5. Computation of Soil Quality Index (SQI)

Soil Quality Index was computed by summing the weighted variable scores. Table 4.13 shows the soil quality index (SQI) computed using non-linear and linear scoring methods. The SQI computed by non-linear scoring method ranged from 0.39 in Meloor (Sample No. 37) to 0.81 in Pariyaram (Sample No. 99) whereas SQI by linear scoring method ranged from 0.56 in Meloor (Sample No. 37) to 0.98 in Kuzhur (Sample No. 8). The soil quality index computed through non-linear and linear scoring methods had a significant positive correlation (0.79^{**}). The range and mean values of SQI in different *panchayats* are presented in Table 4.14**.**

4.8. Relative Soil Quality Index (RSQI)

The Relative Soil Quality Index as per non-linear scoring method ranged from 36.66 per cent in Meloor (Sample No. 37) to 76.46 per cent in Pariyaram *panchayat* (Sample No. 99); whereas, it varied from 40.59 per cent in Meloor (Sample No. 37) to 71.08 per cent in Kuzhur (Sample No. 8) as per linear scoring method (Table 4.13). The relative soil quality index was poor (<50%) in 13 locations, medium in 82 locations (50-70%) and high in 5 locations (>70%) as per the non-linear scoring method. RSQI as per linear scoring method was poor (<50%) in 13 locations, medium in 86 locations (50-70%) and high in one location (>70%). The range and mean values of RSQI in different *panchayats* are presented in Table 4.15**.** The spatial distribution of RSQI classes in sampling locations is depicted in Plate 4.8.

4.9. Preparation of GIS maps

Geo-referenced thematic maps of soil parameters v*iz.*, pH, available nitrogen, available potassium, available magnesium, available boron, organic carbon, microbial biomass carbon, and RSQI were prepared using Arc GIS 10.1 software with IDW (inverse distance weighted) spatial analyst tool (Plates 4.1-4.8).

Table 4.13. Soil quality index (SQI) and relative soil quality index (RSQI)

Sample No	Non-linear scoring		Linear scoring	
	SQI	RSQI (%)	SQI	RSQI (%)
1	0.72	67.55	0.86	62.21
2	0.65	61.59	0.77	55.88
3	0.60	56.15	0.68	49.03
4	0.57	53.65	0.77	55.66
5	0.54	51.41	0.83	60.29
6	0.54	50.85	0.71	51.62
7	0.59	55.20	0.73	52.70
8	0.79	74.43	0.98	71.08
9	0.62	58.54	0.85	61.93
10	0.62	58.61	0.76	55.27
11	0.56	52.46	0.82	59.29
12	0.64	60.12	0.80	57.89
13	0.60	56.81	0.85	61.50
14	0.66	62.66	0.83	59.80
15	0.54	50.56	0.80	57.93
16	0.60	56.61	0.76	55.05
17	0.58	54.93	0.73	52.82
18	0.53	49.98	0.67	48.50
19	0.66	62.29	0.83	60.25
20	0.54	50.53	0.70	50.89
21	0.55	52.08	0.77	55.71
22	0.56	52.69	0.70	50.49
23	0.50	47.32	0.61	43.99
24	0.65	61.19	0.85	61.77
25	0.64	60.27	0.75	54.30
26	0.53	50.01	0.67	48.84
27	0.47	43.93	0.60	43.72
28	0.64	60.11	0.85	61.65
29	0.47	44.35	0.61	44.21
30	0.55	52.04	0.69	49.94
31	0.52	49.18	0.64	46.06
32	0.52	48.80	0.64	46.37
33	0.47	44.27	0.58	42.26
34	0.47	44.27	0.61	43.86
35	0.57	53.61	0.71	51.36
36	0.63	59.83	0.80	57.83
37	0.39	36.66	0.56	40.59
38	0.60	57.02	0.77	55.72
39	0.53	50.15	0.74	53.49
40	0.66	62.05	0.78	56.25
41	0.60	56.91	0.82	59.10
42	0.66	61.90	0.91	65.75

Sample No	Non-linear		Linear	
	SQI	RSQI (%)	SQI	RSQI (%)
43	0.47	43.96	0.73	52.65
44	0.62	58.55	0.86	62.29
45	0.60	56.64	0.80	57.67
46	0.68	64.12	0.82	59.46
47	0.60	56.74	0.93	67.17
48	0.68	64.49	0.83	59.95
49	0.70	66.04	0.90	65.21
50	0.57	53.92	0.79	56.98
51	0.51	47.97	0.74	53.93
52	0.55	51.97	0.70	50.95
53	0.63	59.57	0.86	62.49
54	0.63	59.07	0.81	58.61
55	0.66	61.84	0.82	59.10
56	0.70	66.13	0.86	62.05
57	0.55	52.26	0.82	59.14
58	0.79	74.32	0.95	68.65
59	0.57	53.81	0.71	51.31
60	0.57	53.67	0.79	57.34
61	0.59	55.60	0.82	59.60
62	0.55	52.19	0.85	61.72
63	0.63	59.24	0.86	61.99
64	0.60	56.53	0.79	56.99
65	0.62	58.62	0.88	64.09
66	0.63	59.27	0.82	59.37
67	0.70	65.74	0.93	67.67
68	0.55	51.99	0.76	54.71
69	0.58	55.18	0.86	62.18
70	0.75	70.76	0.86	62.46
71	0.53	50.00	0.76	55.39
72	0.57	53.42	0.78	56.77
73	0.68	63.90	0.92	66.62
74	0.54	50.99	0.79	57.09
75	0.62	58.59	0.85	61.75
76	0.58	54.71	0.90	65.22
77	0.58	55.13	0.85	61.57
78	0.56	53.08	0.84	60.82
79	0.59	55.42	0.90	64.94
80	0.56	52.76	0.68	49.47
81	0.62	58.29	0.82	59.25
82	0.68	63.98	0.85	61.57
83	0.60	56.83	0.82	59.26
84	0.65	61.25	0.81	59.03

Sample No	Non-linear		Linear	
	SQI	**RSQI (%)**	**SQI**	**RSQI (%)**
85	0.50	47.32	0.72	51.87
86	0.60	56.57	0.81	58.49
87	0.56	52.57	0.74	53.63
88	0.59	55.45	0.82	59.71
89	0.59	55.72	0.74	53.56
90	0.66	62.63	0.77	55.45
91	0.61	57.18	0.72	52.29
92	0.58	54.54	0.72	52.15
93	0.74	70.07	0.95	69.06
94	0.73	69.17	0.94	68.09
95	0.55	51.75	0.69	50.14
96	0.61	57.83	0.89	64.23
97	0.71	67.43	0.86	62.24
98	0.64	60.79	0.85	61.64
99	0.81	76.46	0.96	69.26
100	0.74	69.90	0.89	64.34

Table 4.14. Range and mean values of SQI in different *panchayats*

Panvchayat	Non linear scoring			Linear scoring		
	Mean	SD	Range	Mean	SD	Range
Kuzhur	0.60	0.07	0.53-0.79	0.79	0.07	0.67-0.98
Meloor	0.55	0.08	0.39-0.66	0.71	0.10	0.56-0.91
Annamanada	0.62	0.06	0.51-0.70	0.82	0.06	0.70-0.93
Kadukutty	0.62	0.07	0.55-0.77	0.83	0.07	0.71-0.95
Koratty	0.62	0.11	0.53-0.75	0.83	0.06	0.76-0.86
Alagappanagar	0.60	0.06	0.54-0.68	0.84	0.06	0.78-0.92
Thrikkur	0.58	0.01	0.56-0.57	0.87	0.03	0.84-0.90
Kodakara	0.61	0.05	0.56-0.68	0.79	0.07	0.68-0.85
Pudukad	0.58	0.06	0.50-0.65	0.77	0.05	0.72-0.81
Chalakudy	0.64	0.07	0.58-0.74	0.81	0.10	0.72-0.95
Pariyaram	0.68	0.09	0.55-0.81	0.86	0.09	0.69-0.96

Table 4.15. Range and mean values of RSQI in different *panchayats*

Panvchayat	Non linear scoring			Linear scoring		
	Mean (%)	SD	Range (%)	Mean (%)	SD	Range (%)
Kuzhur	57.00	6.23	49.98-74.43	56.92	5.27	48.50-71.08
Meloor	51.84	7.31	36.66-62.05	51.37	7.11	40.59-65.75
Annamanada	58.41	5.38	47.97-66.04	59.48	4.50	50.95-67.17
Kadukutty	58.41	6.71	51.99-74.32	60.36	4.84	51.31-68.65
Koratty	58.65	10.81	50.00-70.76	60.01	4.00	55.39-62.46
Alagappanagar	56.73	5.74	50.99-63.90	60.56	4.64	56.77-66.61
Thrikkur	54.59	1.05	53.08-55.42	63.14	2.27	60.82-65.22
Kodakara	57.97	4.64	52.76-63.98	57.39	5.39	49.47-61.57
Pudukad	54.43	5.92	47.32-61.25	55.76	3.55	51.87-59.03
Chalakudy	60.68	6.66	54.54-70.07	58.62	7.27	52.15-69.06
Pariyaram	64.03	8.95	51.75-76.46	61.98	6.39	50.14-69.25

Plate 4.1. Spatial distribution of soil reaction classes in sampling locations

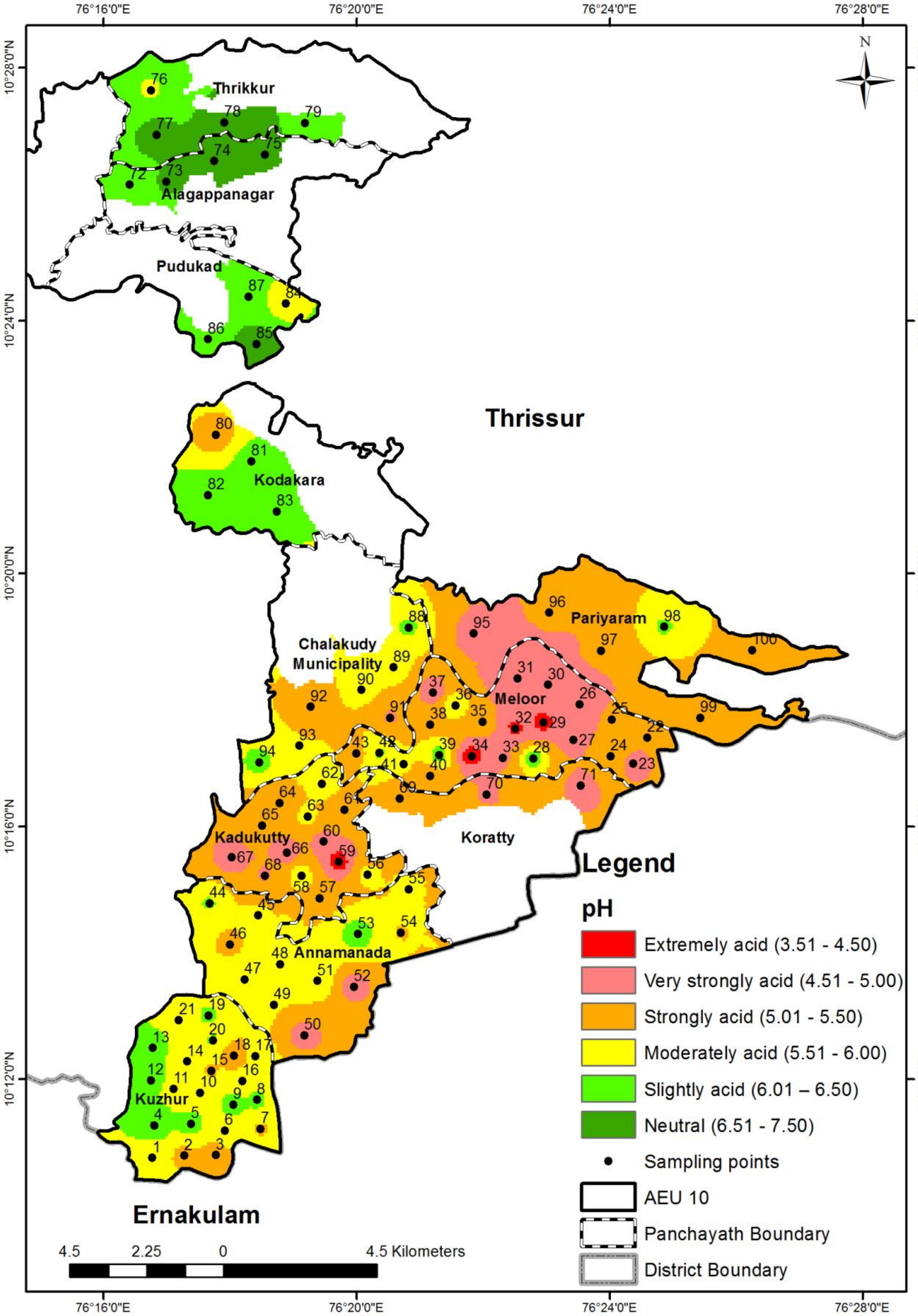


Plate 4.2. Spatial distribution of available N classes in sampling locations

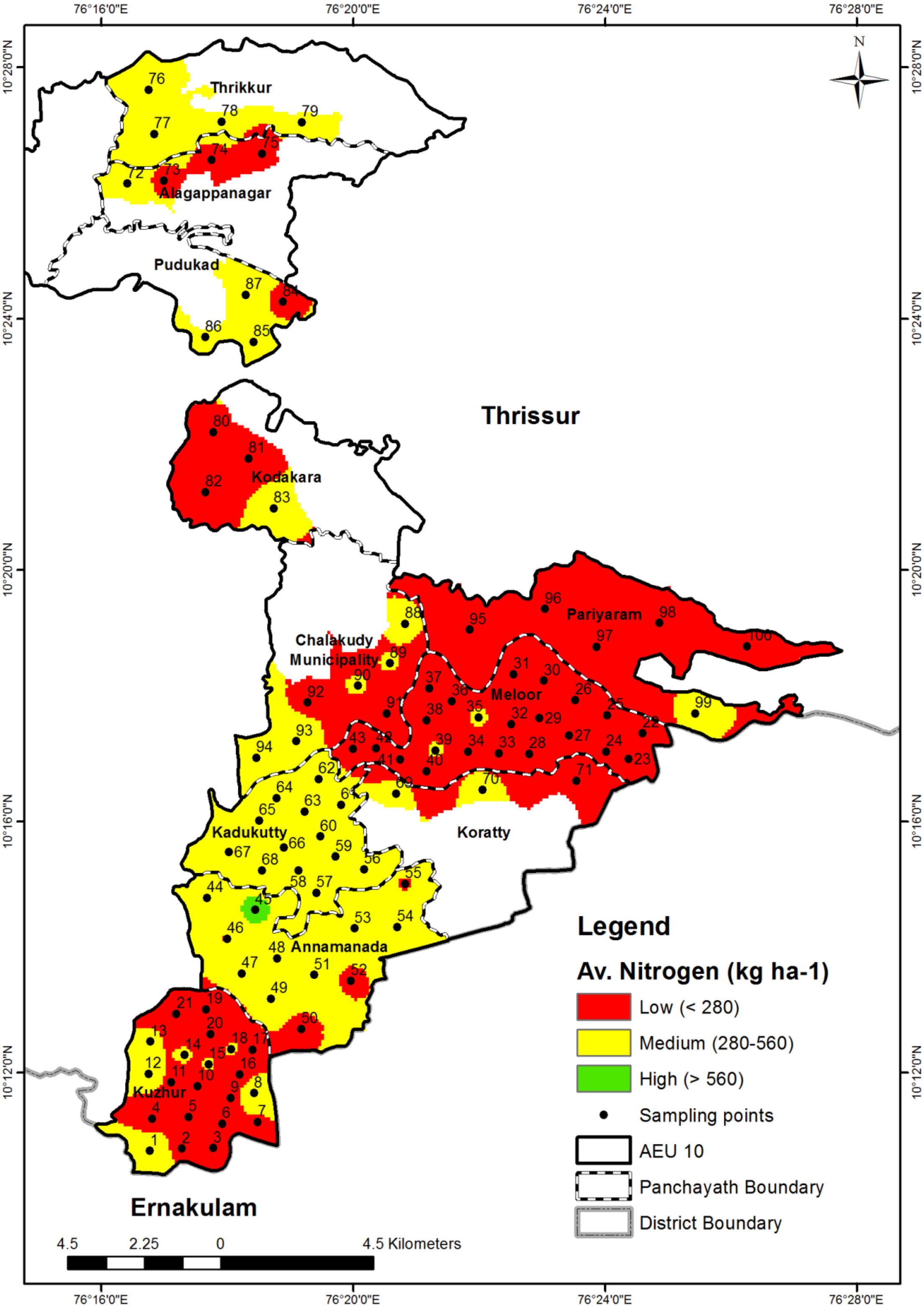


Plate 4.3. Spatial distribution of available K classes in sampling locations

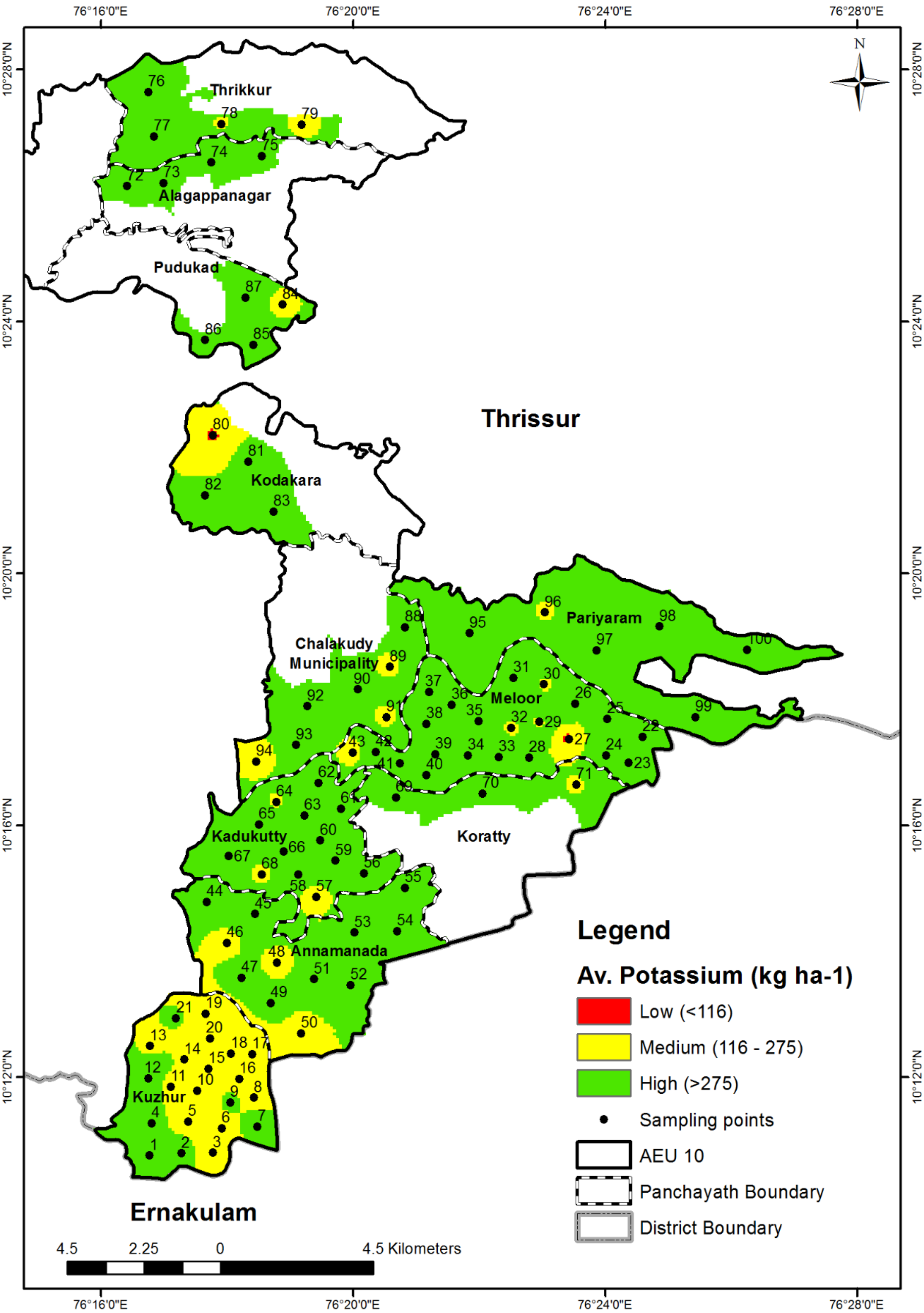


Plate 4.4. Spatial distribution of available Mg classes in sampling locations

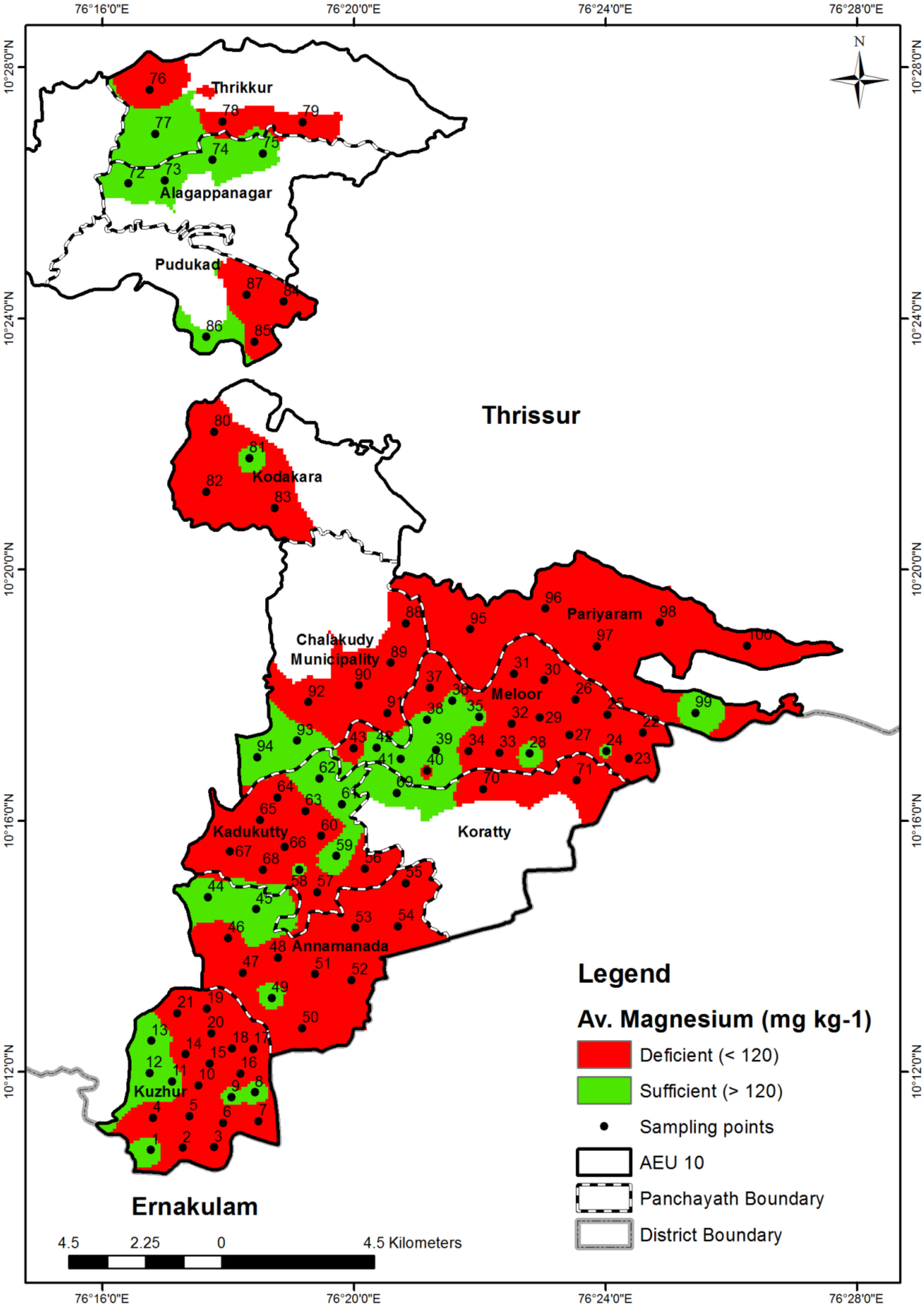


Plate 4.5. Spatial distribution of available B classes in sampling locations

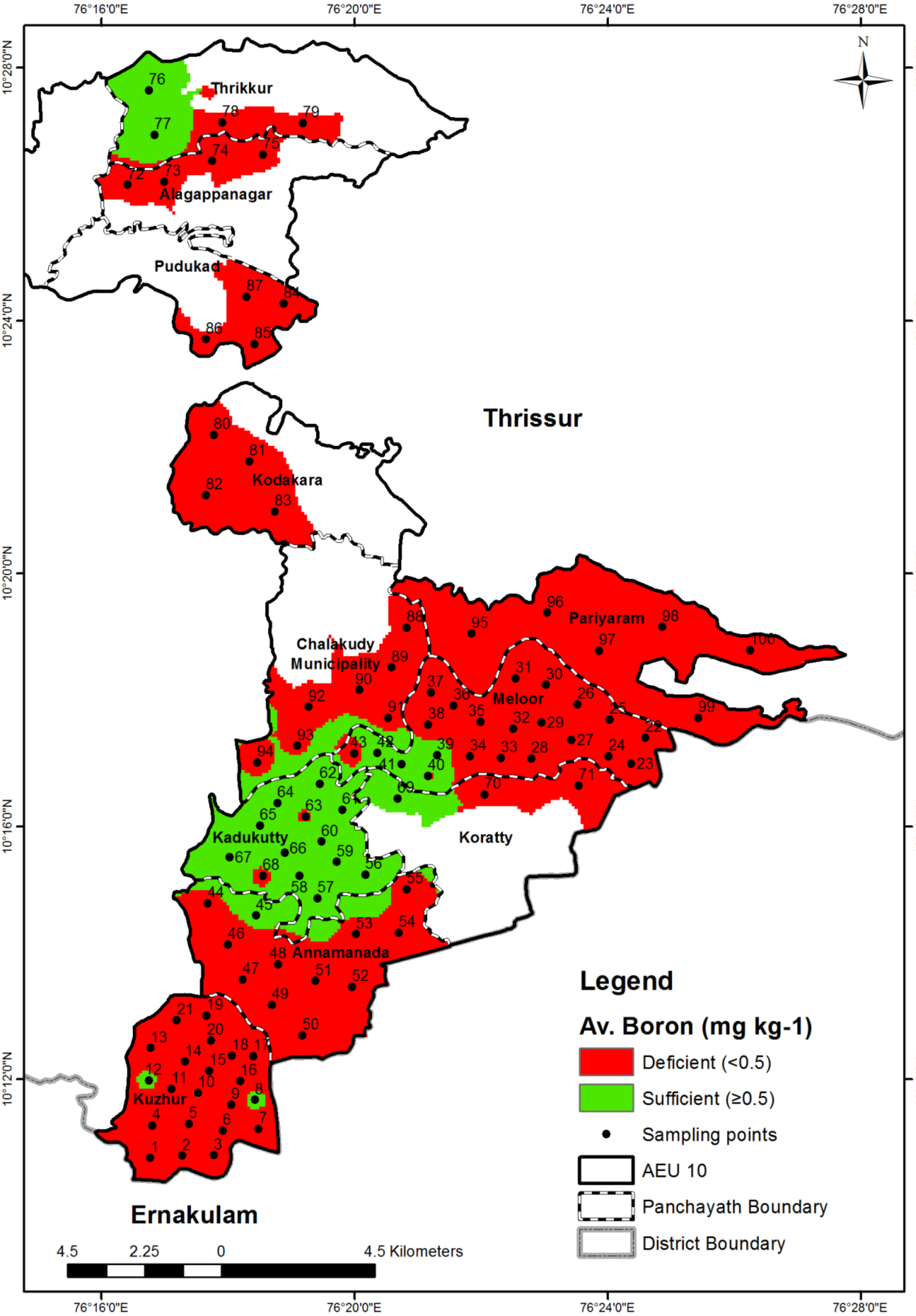


Plate 4.6. Spatial distribution of organic carbon classes in sampling locations

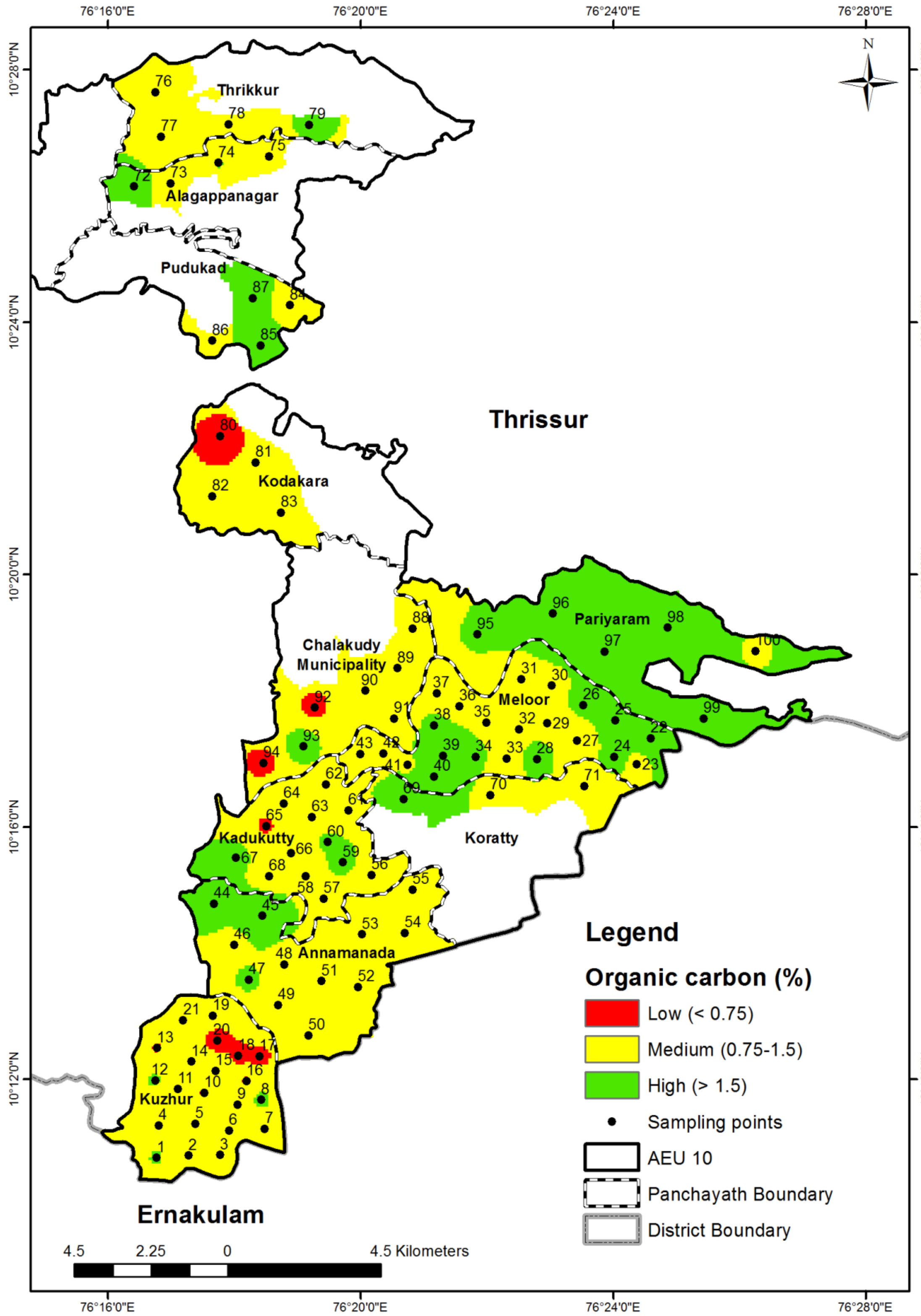


Plate 4.7. Spatial distribution of MBC classes in sampling locations

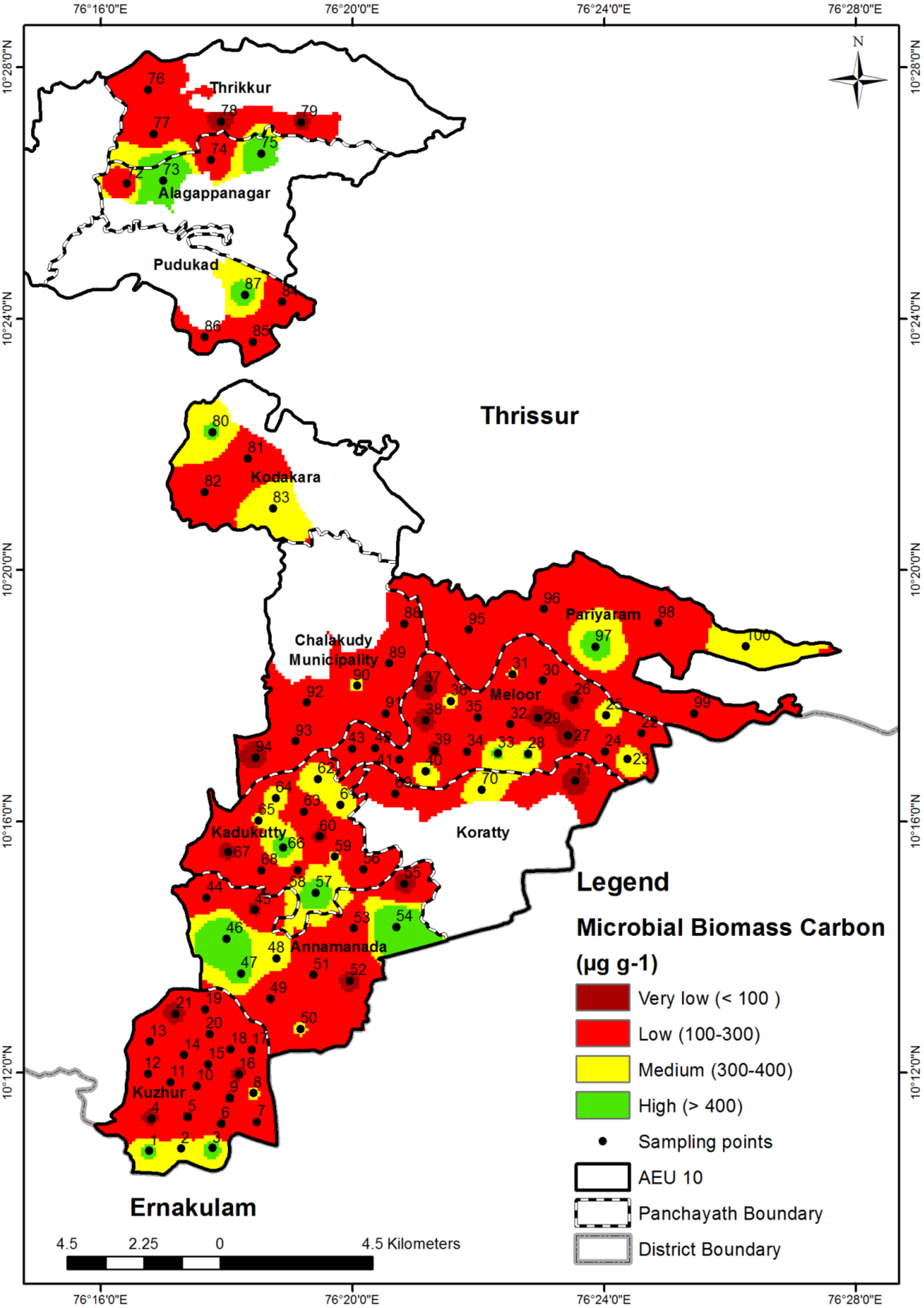
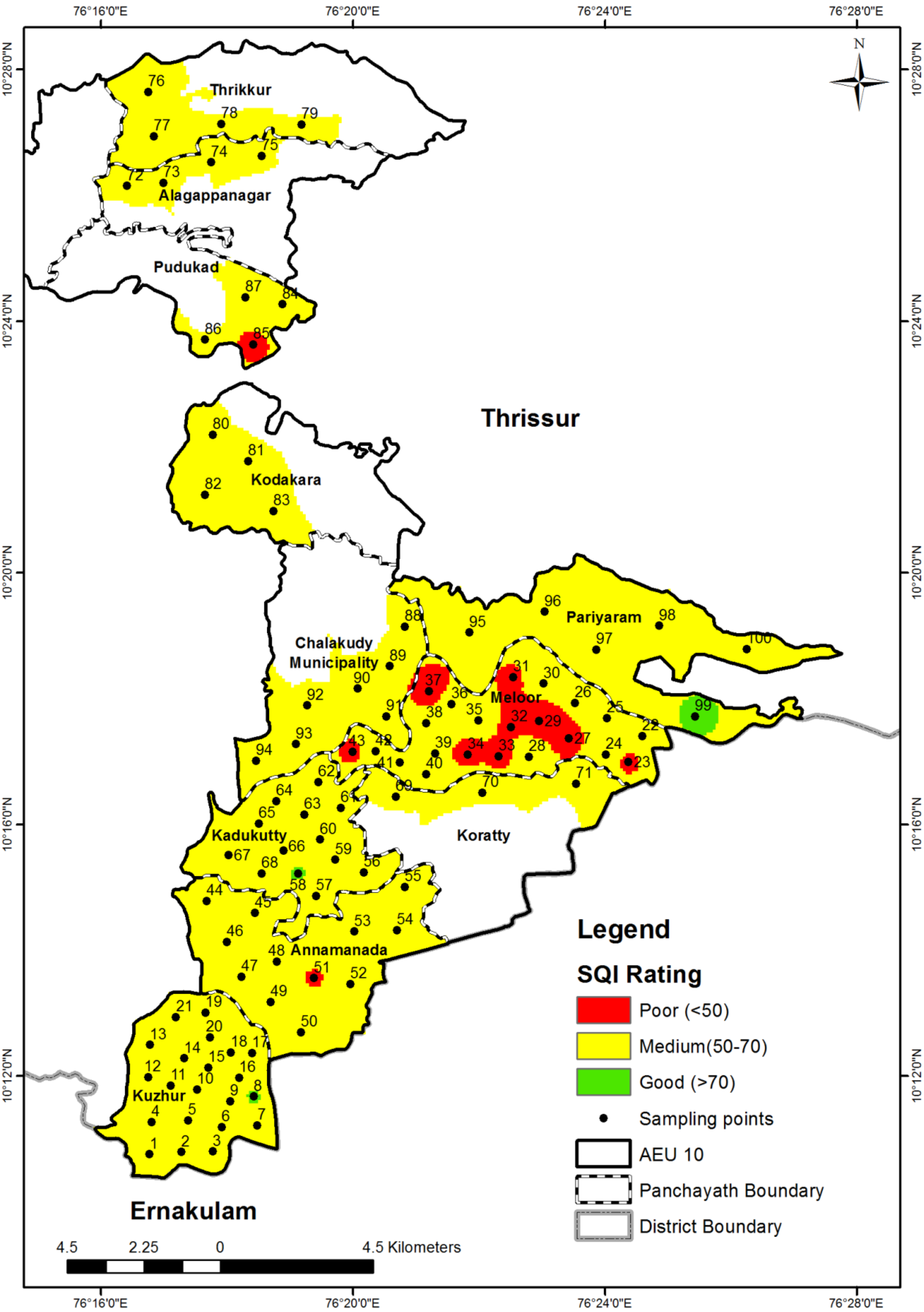


Plate 4.8. Spatial distribution of RSQI in sampling locations



Discussion

5. DISCUSSION

The present study was undertaken to assess the soil quality of post flood soils of AEU 10 in Thrissur district and workout soil quality index, develop maps on important soil characteristics using GIS techniques. One hundred composite soil samples were collected from eleven *panchayats* of AEU 10 (North Central Laterites) in Thrissur district of Kerala and soil quality parameters were analysed in the laboratory. The analytical results presented in the Chapter 4 are critically discussed here with relevant literature.

5.1. Physical attributes

5.1.1. Bulk density (BD)

The ratio of the mass of oven-dried soil to its bulk volume is known as bulk density. It includes the volume of soil particles as well as the pore spaces. Bulk density is the indicator of soil compaction and restriction to root growth (Arshad *et al.,* 1996). Several factors including soil porosity, mineral type, organic matter content, texture and structure influence bulk density (Chaudhari *et al.*, 2013). The mean bulk density of soil ranged from 1.07 Mg m^{-3} in Pariyaram to 1.58 Mg m^{-3} in Kodakara (Fig 5.1a). Thirty eight per cent of the samples exhibited bulk density below 1.20 Mg m^{-3} and forty four per cent had a BD between 1.20 and 1.40 Mg m^{-3} and eighteen per cent recorded BD above 1.40 Mg m^{-3} (Fig 5.2a). Eighty two per cent of the samples including all samples of Meloor and Pariyaram had a bulk density below 1.40 Mg m^{-3}. This can be corroborated with the finding that 86 per cent samples had medium to high content of organic carbon with significantly higher content in Pariyaram and Meloor *panchayats*.

5.1.2. Particle density (PD)

Particle density of the samples ranged from 1.75 Mg m^{-3} to 2.40 Mg m^{-3}. The mean particle density of soils varied from 2 Mg m^{-3} in Pariyaram to 2.14 Mg m^{-3} in Thrikkur. Seventy six per cent of the samples had a PD between 2.00 and 2.20 Mg m^{-3} (Fig 5.2b). Average PD of all the *panchayats* was below 2.20 Mg m^{-3} (Fig 5.1b). The variation in particle density of surface soils can be contributed to the presence of organic matter (Thomas, 2010).

5.1.3. Porosity

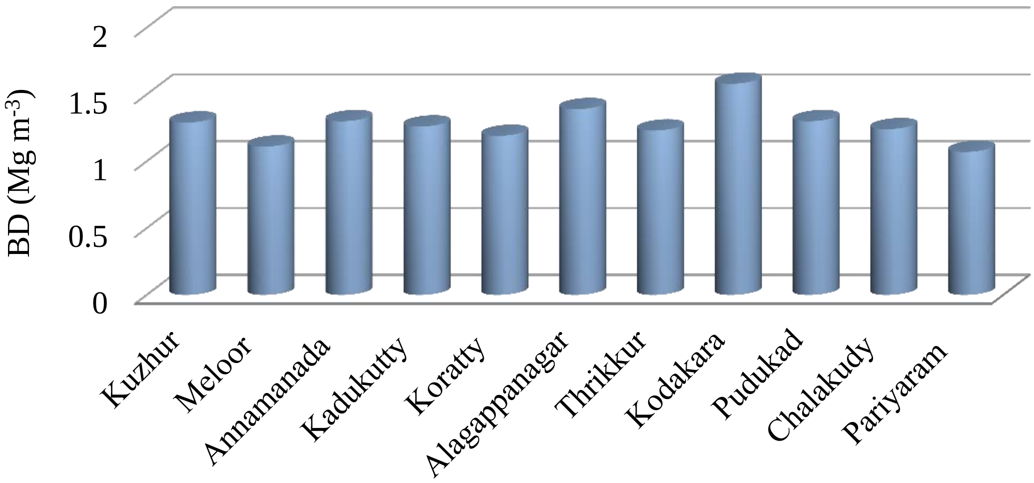
Porosity refers to the per cent soil volume occupied by pores. The volume and distribution of pores in soil is directly related to the gaseous movement within the soil as well as between soil and atmosphere. The range of porosity varied between 34.00 and 52.69 per cent. All the soil samples studied had medium to high per cent of porosity (Pal, 2013). Ninety six per cent of the samples showed porosity in medium range of 30 and 50 per cent (Fig 5.2c). Maximum average porosity of 45.62 per cent was noted in Meloor and minimum average porosity of 38.11 per cent was observed in Kodakara (Fig 5.1c). The higher porosity observed in soils can be supported by the lower BD observed in these soils. Similar findings were reported by Lee *et al.* (2009).

5.1.4. Maximum water holding capacity (WHC)

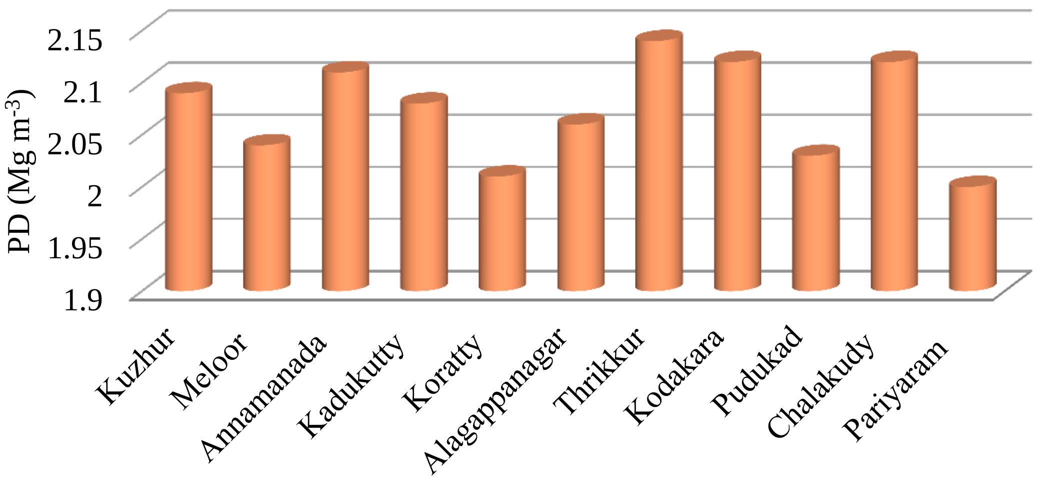
Highest average water holding capacity (WHC) in the samples ranged from 26.48 per cent in Kodakara to 36.38 per cent in Pariyaram. The water holding capacity of all the soils was in the medium (20-50%) range (Saha, 2008). All the *panchayats* had an average WHC of >30 per cent except Kodakara (Fig 5.1d). The WHC was between 30 and 40 per cent in 71 per cent of the samples and less than 30 per cent in 26 per cent samples (Fig 5.2d). Increase in specific surface area of the soil due to deposition of clay and organic matter might have contributed to the higher WHC (Asadi *et al.*, 2009).

Fig 5.1. Mean values of soil physical parameters in different *panchayats*

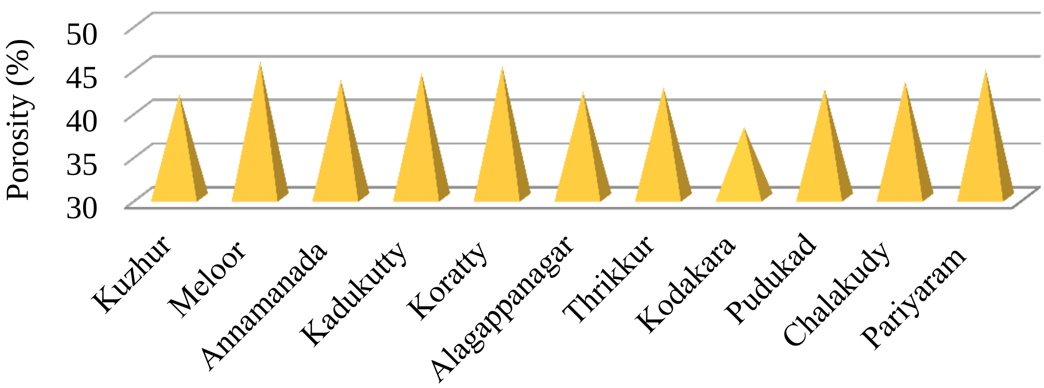
a. Bulk density



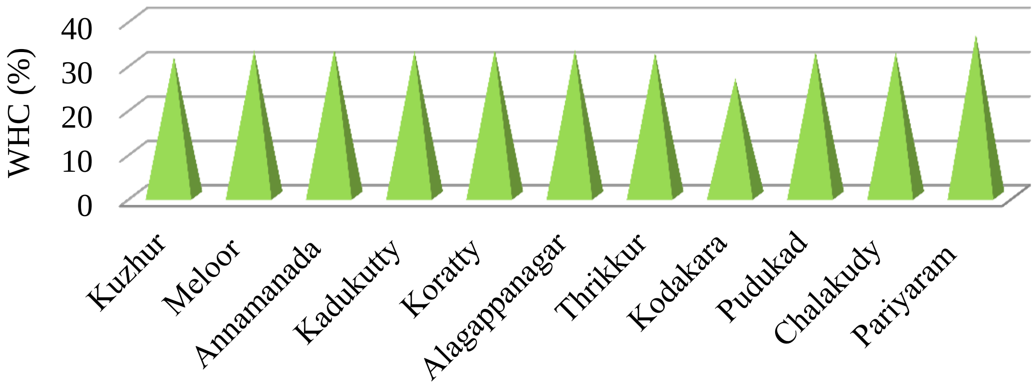
b. Particle density



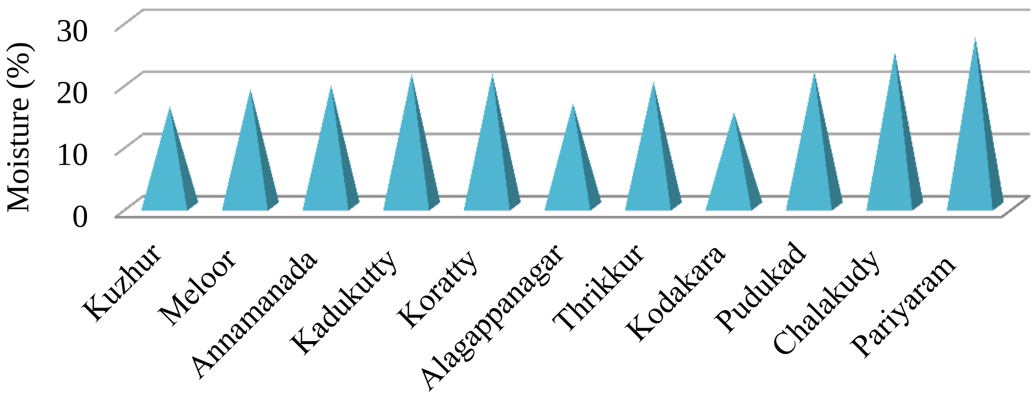
c. Porosity



d. Maximum water holding capacity



e. Moisture content



f. Aggregate stability

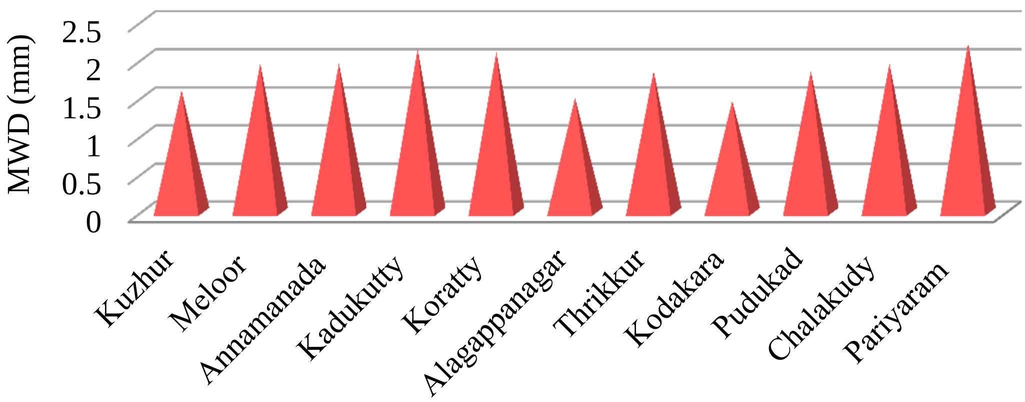
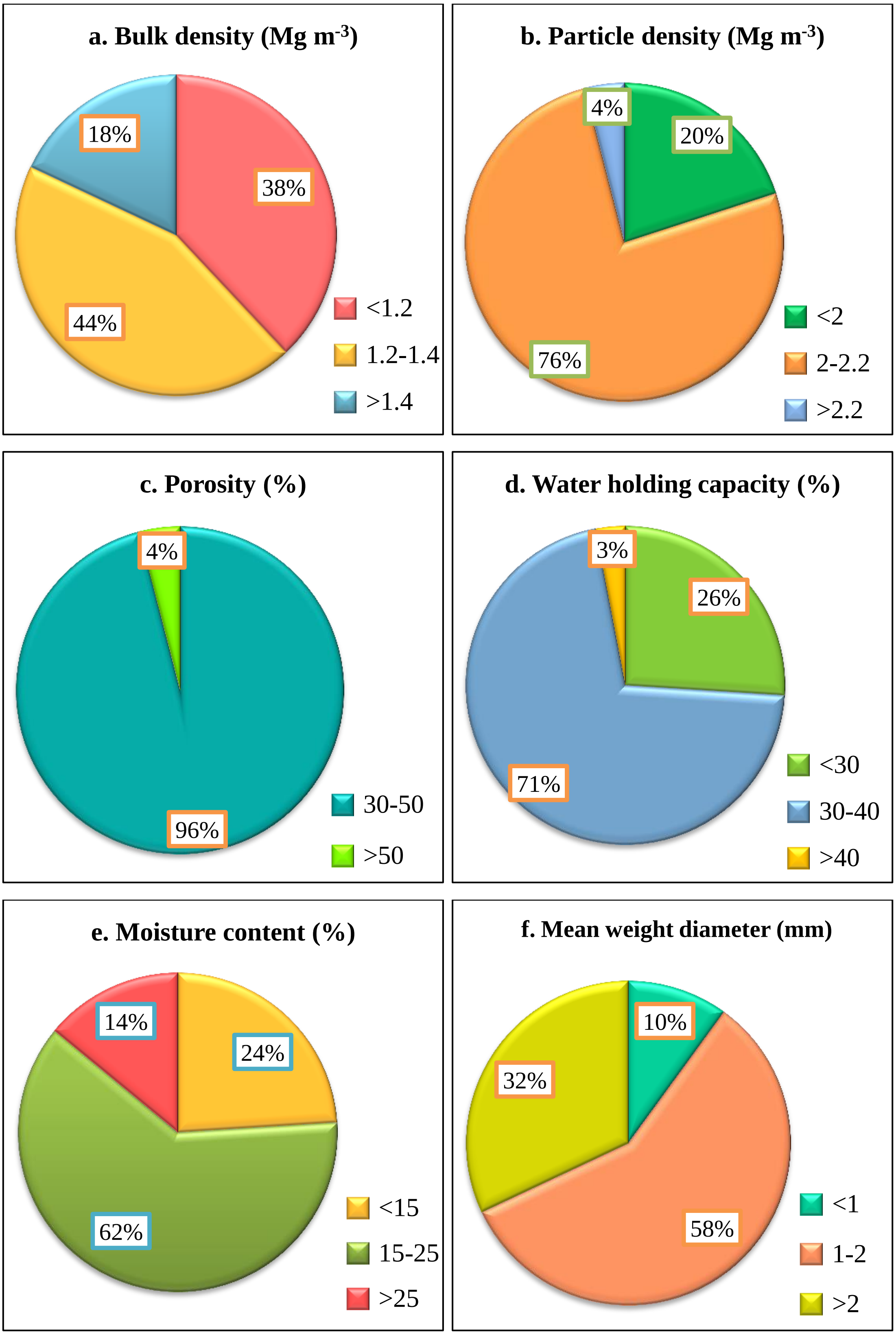


Fig 5.2. Frequency distribution of soil physical parameters in different classes



5.1.5. Soil moisture content (SMC)

The average soil moisture content at the time of sample collection ranged from 15.21 per cent in Kodakara to 27.31 per cent in Pariyaram. The SMC was between 15 and 25 per cent in 62 per cent samples (Fig 5.2e) and more than 25 per cent in 14 per cent samples. The average SMC was less than 25 per cent in all *panchayats* (Fig 5.1e) except Pariyaram (27.31%). The soil was fully saturated during flood but as the samples were collected about six months later, water in the pores was replaced by air. Lower soil moisture content was observed in the uplands compared to lowlands and thus, contributed to the wide variation of moisture in the samples.

5.1.6. Aggregate stability

Aggregates are the group of primary soil particles (sand, silt, clay) occurring naturally. The stability of soil aggregates was measured against the action of water. The water stable aggregates was expressed in terms of mean weight diameter (MWD). The mean value ranged from 1.46 mm in Kodakara to 2.22 mm in Pariyaram. The MWD of 58 per cent of the samples was between 1 and 2 mm while, 32 per cent samples had a value greater than 2 mm (Fig 5.2f). The average MWD was greater than 1.40 mm in all *panchayats* (Fig 5.1f). A strong positive correlation was observed between MWD of the samples and the organic carbon content. Carbon compounds in the organic matter is involved in binding primary soil particles especially in soil poor in clay content (Khazaei *et al.*, 2008).

5.2. Electrochemical attributes

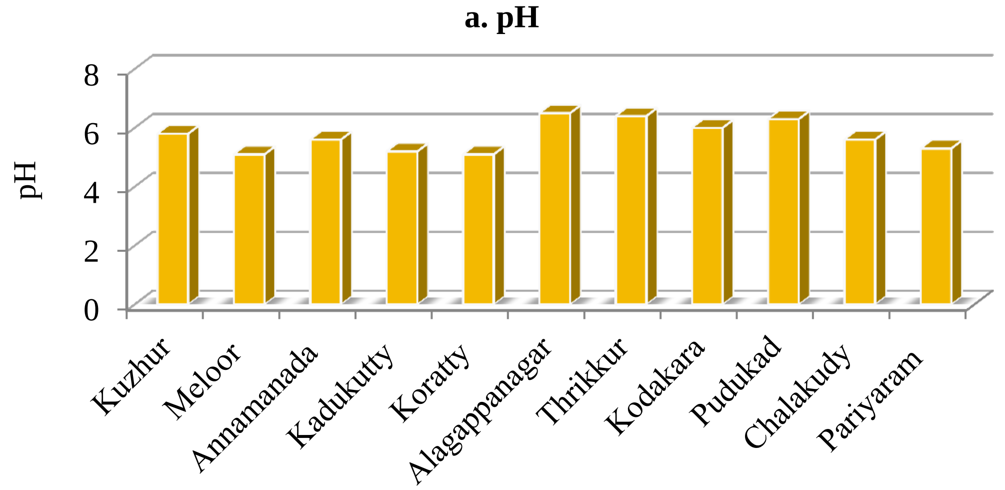
5.2.1. Soil pH

Availability of nutrients in soil as well as the activity of soil micro-organisms highly depend on soil pH. The optimum soil pH range for nutrient availability and microbial activity is 6.0 to 7.5 (Smith and Doran, 1996). The analysis of surface soil from flood affected areas displayed dominance of acidic reaction with pH ranging from 4.1 to 7.0. Ninety two per cent of samples were acidic in reaction with pH below 6.5. The mean soil pH of all other *panchayats* except Alagappanagar, Thrikkur, Pudukad and Kodakara were below 6 (Fig 5.3a). Twenty four per cent of the samples exhibited strong acidity (pH 5.01-5.50) and twenty two per cent moderate acidity (5.51-6.00). Nineteen per cent was very strongly acidic (pH 4.51-5.00), and four per cent including all samples from Meloor were extremely acidic (pH 3.50-4.50) (Fig 5.4). According to Sujatha *et al.* (2013) the soils of North Central Laterites are in general strongly to moderately acidic in reaction. The acidity of soil might be due to high rainfall and leaching of bases from surface soil. Soil pH range of 3.5 to 7.3 in the study area prior to floods was reported by Venugopal *et al.* (2019). Hence, no much variation in soil pH can be attributed to the influence of flood.

5.2.2. Electrical conductivity (EC)

Electrical conductivity of the soil solution expresses the salinity status of the soil with respect to plant growth. The EC of soil samples ranged between 0.03 dS m^{-1} and 0.89 dS m^{-1}, which is within the critical limit for plant growth and hence might not have any significant influence on soil quality. Average values of EC in different *panchayats* are shown in Fig 5.3b**.** The low EC in soil is due to leaching of salts triggered by high rainfall.

Fig 5.3. Mean values of electrochemical attributes in different *panchayats*



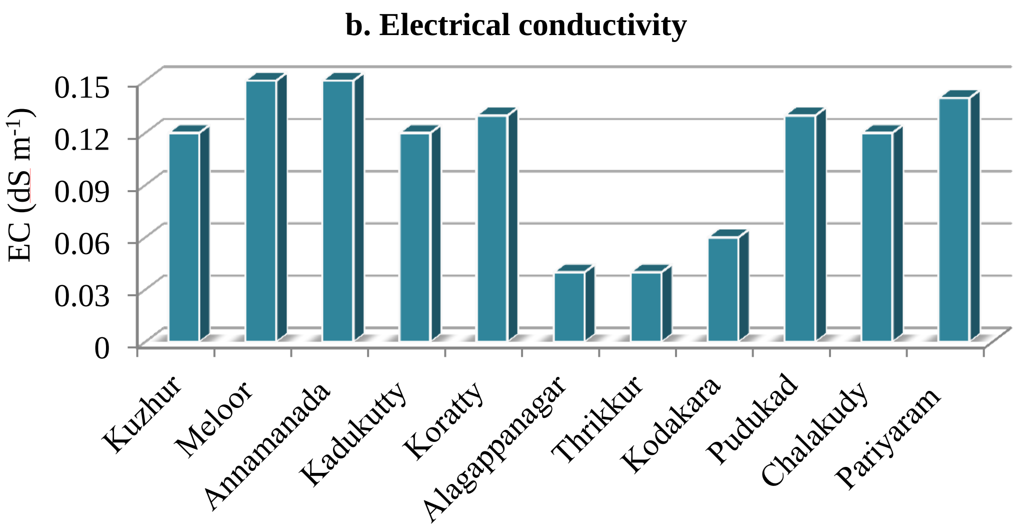
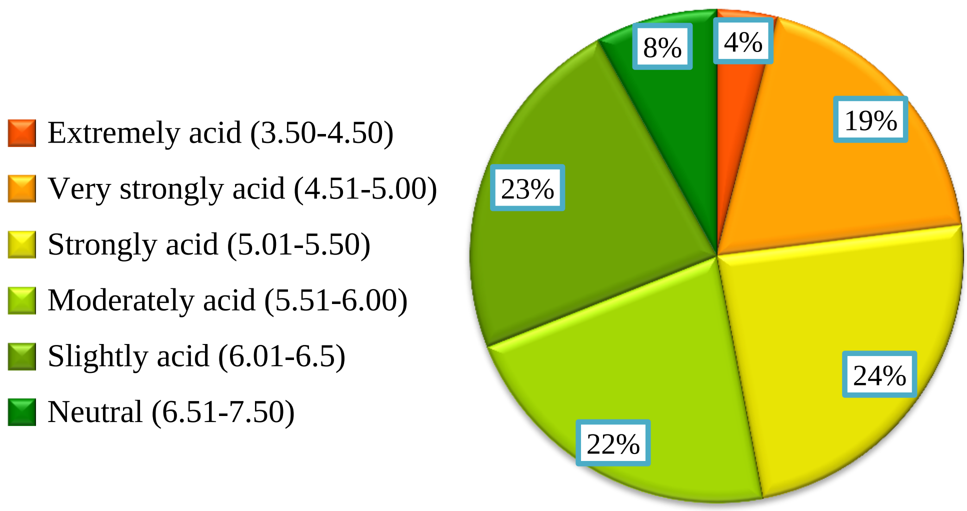


Fig 5.4. Frequency distribution of soil reaction classes



5.3. Chemical attributes

5.3.1. Available nitrogen (Av. N)

Nitrogen is considered as the most important functional nutrient and structural component of plants. The availability of nitrogen in soil is dependent on organic carbon content as more than ninety five per cent of nitrogen is organically bound and C:N ratio in soil is stabilized at 10:1 (Sureshkumar *et al.*, 2013). Av. N was observed to vary from as low as 67.74 kg ha^{-1} in Meloor to a maximum value of 719.71 kg ha^{-1} in Annamanda. Fifty three per cent of the samples were low (<280 kg ha^{-1}) and forty five per cent medium in status (280-560 kg ha^{-1}) of Av. N (Fig 5.7a). The highest mean value of 389.17 kg ha^{-1} was recorded in Kadukutty and the lowest of 146.25 kg ha^{-1} in Meloor (Fig 5.5a). The average value for available nitrogen in soil was more than 280 kg ha^{-1} in Annamanda, Kadukutty, Koratty, Thrikkur, Pudukkad and Chalakudy. Though Sujatha *et al*. (2013) reported that only 17 per cent of soils in AEU 10 of Thrissur district were deficient in available nitrogen, the present study revealed that more than fifty percent of sampling locations in the flood affected areas were deficient in nitrogen. Hence, the limitation in availability of nitrogen is a major constraint to soil quality.

5.3.2. Available phosphorus (Av. P)

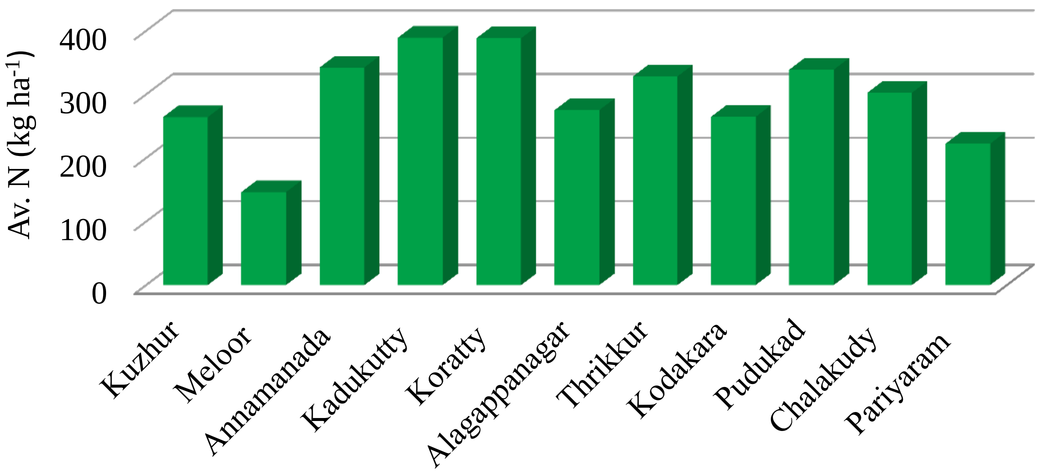
Available P is the key component of energy metabolism and biosynthesis of nucleic acids. It is the second most limiting nutrient for plant after nitrogen. However in the present study, available phosphorus content was found to be very high in all the soil samples and ranged from 48.00 to 851.79 kg ha^{-1}. Content of Av. P was extremely high (>100 kg ha^{-1}) in ninety per cent of the samples (Fig 5.7b). Around 70 per cent soils of Thrissur district was reported to have very high (36-100 kg ha^{-1}) and extremely high (>100 kg ha^{-1}) content of available phosphorus (KAU, 2018). The average content was more than 100 kg ha^{-1} in all the *panchayats* (Fig 5.5b). Excess levels of Av. P in 76 per cent soils of North Central Laterites of Thrissur district was also reported by Sujatha *et al*. (2013). Dissolution of mineral phosphorus under acidic reaction and mineralisation of organic phosphorus by the activity of soil microbes might have contributed to high status of Av. P. Available phosphorus is contributed mainly by soluble and calcium bound phosphorus existing in the form of mono calcium phosphate which is in dynamic equilibrium with other inorganic fractions (Geetha, 2008). The results point to the scope of skipping phosphatic fertilizers in cases of excess levels in soil as it may induce zinc and boron deficiencies.

5.3.3. Available potassium (Av. K)

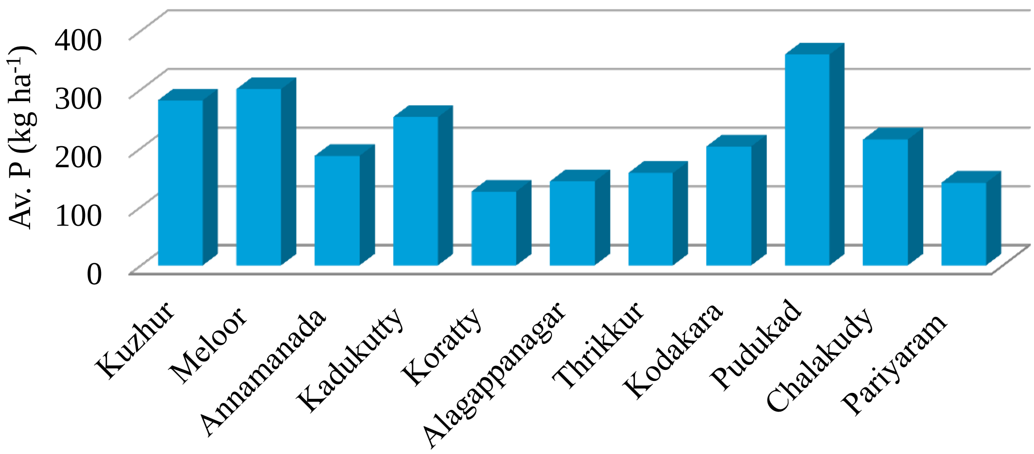
Available potassium in soil was found to vary from 94.64 to 2229.47 kg ha^{-1}. Plants require a large quantity of potassium to complete their life cycle which involves strengthening the defence system and osmoregulation. Thirty one per cent of samples had medium content (116-275 kg ha^{-1}) and sixty six per cent high (>275 kg ha^{-1}), which includes twenty seven per cent with very high (276-400 kg ha^{-1}) and three per cent with extremely high content (>1000 kg ha^{-1}) (Fig 5.7c) of Av. K (KAU, 2018). Soils of Meloor had the highest mean value of 558.87 kg ha^{-1} and Kodakara the lowest of 251.52 kg ha^{-1} (Fig 5.5c). The average content of Av. K in all *panchayats* except Kuzhur and Kodakara was found to be more than 275.00 kg ha^{-1}. According to DoADFW (2018), Av. K was medium in status in soils of the study area except Thrikkur, where high content was recorded. The deposition of flood alluvium would have contributed to enriching soil with potassium content.

Fig 5.5. Mean values of primary nutrients in different *panchayats*

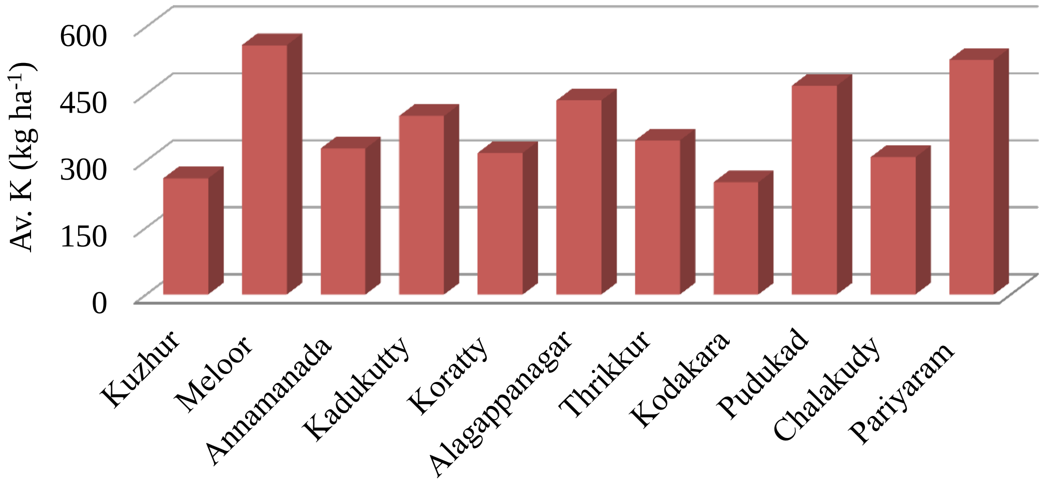
a. Available N



b. Available P



c. Available K



5.3.4. Available calcium (Av. Ca)

Calcium is a secondary nutrient required by crops in quantities lesser than potassium. A high concentration of Av. Ca was observed in the samples, ranging from 233.75 to 2232.00 mg kg^{-1}. Ninety seven per cent of the samples had a concentration greater than 300 mg kg^{-1} (Fig 5.7d); of which thirty one per cent including all samples from Alagappanagar and Thrikkur had values greater than 1000 mg kg^{-1}. The highest mean content of available calcium was found in Pudukkad (1456.81 mg kg^{-1}) and the lowest in Meloor *panchayat* (596.00 mg kg^{-1}) (Fig 5.6a). Sujatha *et al.* (2013) had reported calcium deficiency to the tune of 29 per cent in North Central Laterites of Thrissur district. Most of the *panchayats* of the study area was reported to have sufficient status of available calcium prior to floods (DoADFW, 2018). However, the higher concentration of calcium in the flood affected soils could be due to deposition of calcium rich sediments during the flood. However the higher levels of calcium in soil can interfere with the crop uptake of nutrients like magnesium (Fageria, 2009).

5.3.5. Available magnesium (Av. Mg)

Available magnesium content in soil varied from 23.00 to 345.00 mg kg^{-1}. It was more than 120 mg kg^{-1} in 33 per cent and between 60 and 120 mg kg^{-1} in 55 per cent of the samples (Fig 5.7e). The average content was above 120 mg kg^{-1} in Alagappanagar and Pudukkad (Fig 5.6b); whereas, in the case of all other *panchayats* it varied from 60 and 120 mg kg^{-1}. Venugopal *et al.* (2019) had reported magnesium deficiency in all soils of the study area in the pre flood situation. The deposition of clay in the post flood scenario would have contributed to higher retention of cations. Higher content of organic matter also increase available cations such as K, Ca and Mg by forming soluble complexes (Mayland and Wilkinson, 1989).

5.3.6. Available sulphur (Av. S)

Available sulphur ranged from 48.74 to 149.54 mg kg^{-1} in the studied soils. The content of available S was found to be above the threshold (>5 mg kg^{-1}) level of sufficiency in all the samples. *Panchayat* wise average content of Av. S in soil varied from 75.52 mg kg^{-1} in Chalakudy to 99.96 mg kg^{-1} in Annamanada (Fig 5.6c).

Deficiency of available sulphur was reported by DoADFW (2018) in Alagappanagar, Annamanada, Kadukutty, and Thrikkur *panchayats*. A wide range of available sulphur from 11 mg kg^{-1} to 548 mg kg^{-1} was reported by DSSSC (2018) in the post flood soils of Thrissur District. Sulphur might have been imparted to the available pool by inundated water or excessive application of sulphur containing fertilizers. Waterlogging might have triggered desorption of sulphates adsorbed on hydrous oxides that increased their concentration in soil (Reddy *et al.,* 2001). However, unlike phosphorus sulphur retention in soil is not possible through fixation or reversion (Sureshkumar *et al*, 2013).

5.3.7. Available iron (Av. Fe)

Available iron content in soil ranged from 14.72 to 447.00 mg kg^{-1}. Mean value of Av. Fe was more than 60 mg kg^{-1} in all *panchayats* and was more 100.00 mg kg^{-1} in Kadukutty, Alagappanagar, Thrikkur, Kodakara, Pudukkad and Chalakudy (Fig 5.8a). Deficiency of available iron was reported to be negligible in soils of Thrissur district by Kavitha and Sujatha (2015). Though iron deficiency is not anticipated in acidic soils, toxicity of Fe may occur in very acidic soils ($pH<3.2$) or under anaerobic conditions (Fageria *et al*., 2008). Iron toxicity is seldom observed in well drained soils as it exists in oxidized form (Sureshkumar *et al*., 2018). The high iron content in soil can cause toxicity if anaerobic conditions prevail.

Fig 5.6. Mean values of secondary nutrients in different *panchayats*

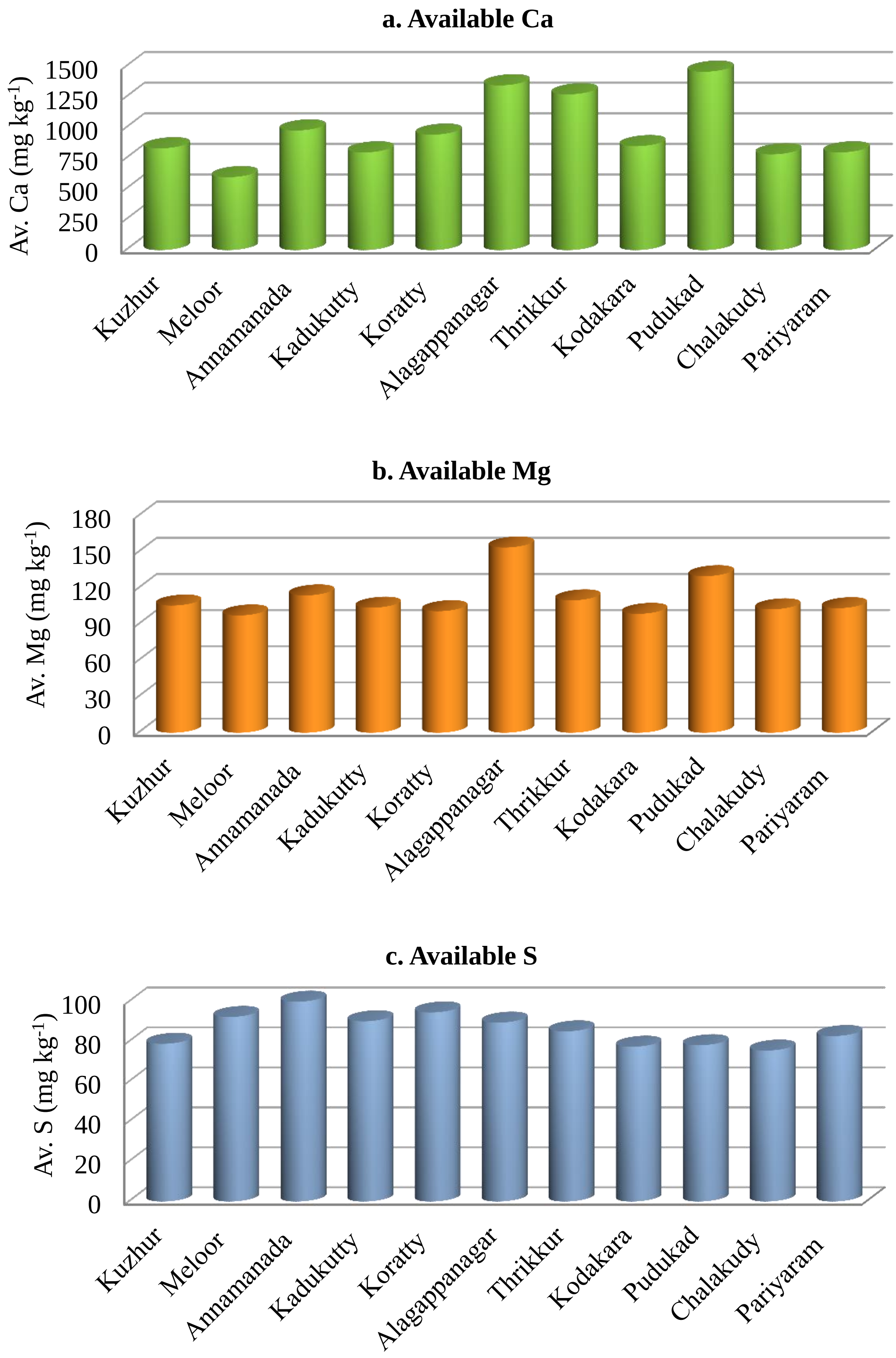
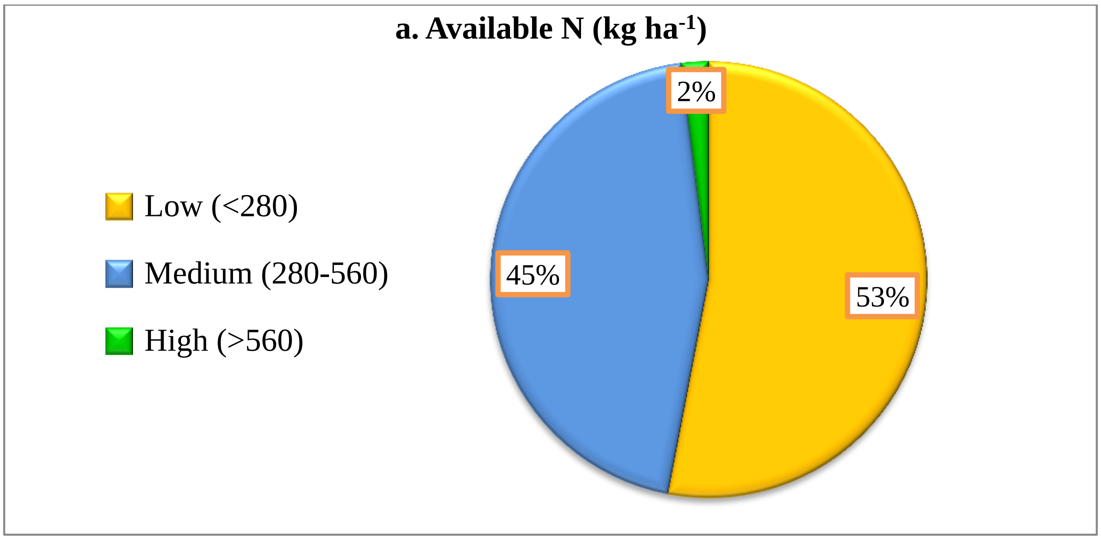
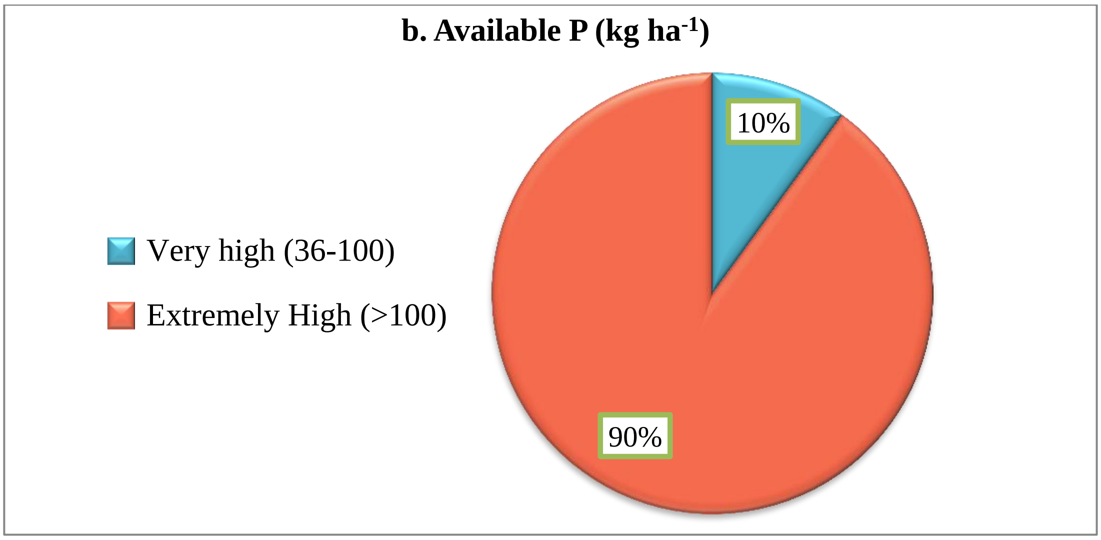
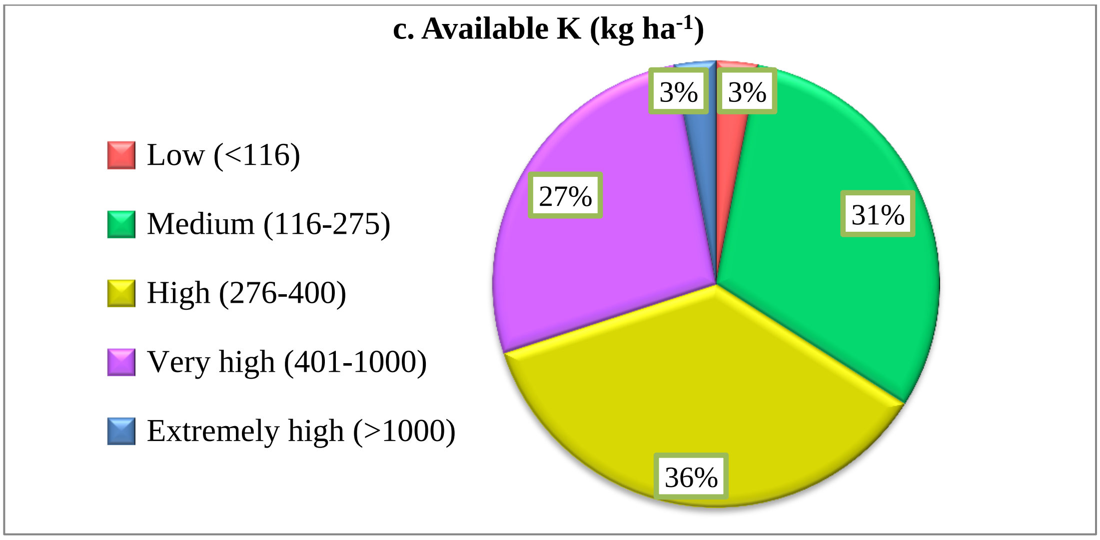
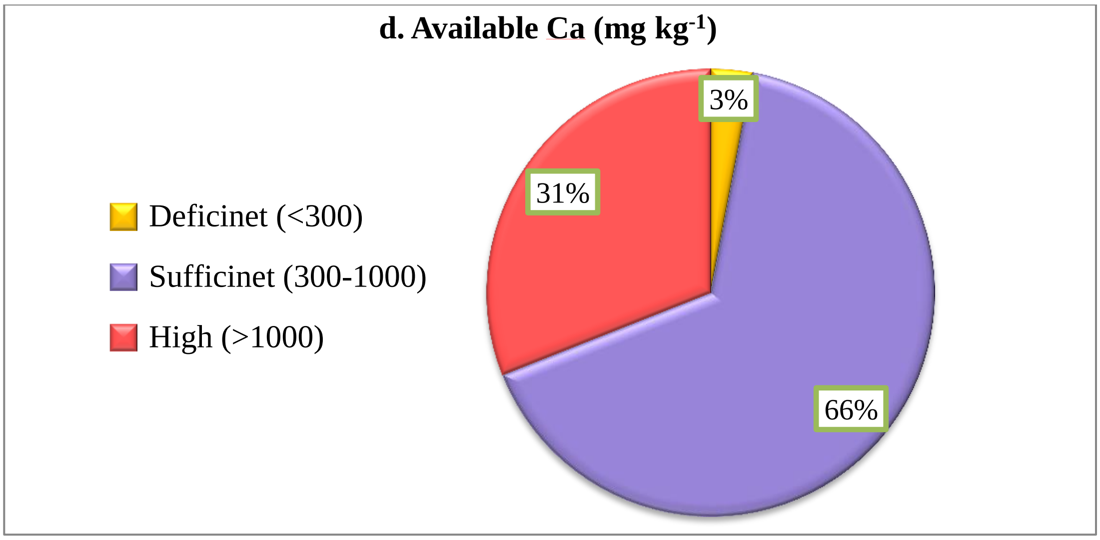


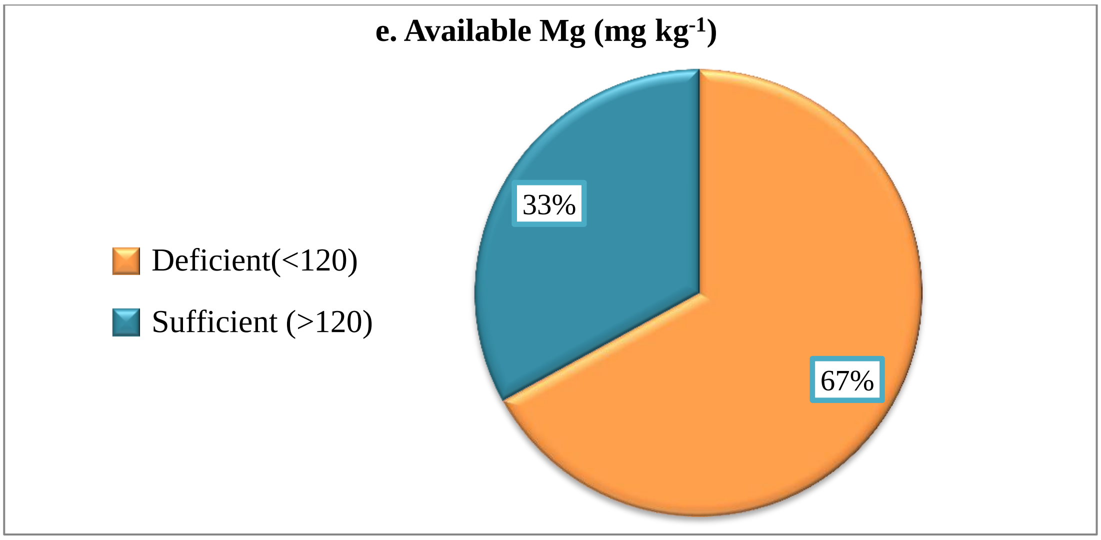
Fig 5.7. Frequency distribution of available nutrients in different classes

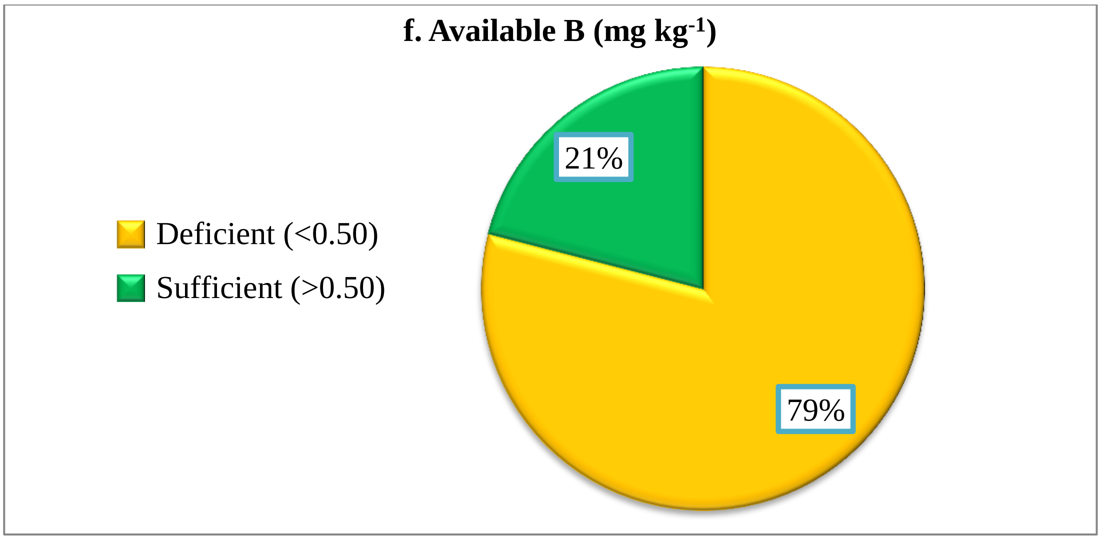







d. Available Ca (mg kg-1)
Deficinet (<300)
Sufficinet (300-1000)
High (>1000)
3%
31%
66%


e. Available Mg (mg kg-1)
Deficient(<120)
Sufficient (>120)
33%
67%


f. Available B (mg kg-1)
Deficient (<0.50)
Sufficient (>0.50)
21%
79%

5.3.8. Available manganese (Av. Mn)

In the case of available manganese, the concentration in soil varied between 3.18 and 129.5 mg kg^{-1} and all the *panchayats* had an average concentration greater than 25.00 mg kg^{-1} soil (Fig 5.8b). Anaerobic environment results in reduction of Fe^{3+} and Mn^{4+} to Fe^{2+} and Mn^{2+} respectively which are more soluble in nature, contributing to the high content of these elements in the soil solution (Fageria *et al.*, 2011). Though reduction reactions are chemical and/or microbiological in nature, oxidation reactions are mostly biological. Further, soil acidity shifts the equilibrium towards release of free metal cations into soil solution. At pH below 5.5, Mn oxides solubilize and releases Mn^{2+} into soil solution (Porter *et al.*, 2004). This emphasizes the need to ameliorate soil acidity through liming.

5.3.9. Available copper (Av. Cu)

Available copper content in the soil samples ranged from 1.52 to 34.50 mg kg^{-1}. Pariyaram had the minimum average concentration of 2.57 mg kg^{-1} soil and the maximum average value of 12.88 mg kg^{-1} was found in Thrikkur (Fig 5.8c). Available copper was found to be deficient in Kadukutty, Koratty and Pariyaram *panchayats* by Venugopal *et al*. (2019) in the pre flood scenario, however the present study on flood affected soils showed no deficiency with respect to available copper content.

5.3.10. Available zinc (Av. Zn)

Available zinc ranged from 0.95 to 55.12 mg kg^{-1} soil. Zinc deficiency was recorded only in one location. The mean value of Av. Zn ranged from 3.47 mg kg^{-1} in Pariyaram *panchayat* to 22.35 mg kg^{-1} in Pudukad (Fig 5.8d). According to Venugopal *et al.* (2019) zinc deficiency is negligible in the soils of Kerala. Sufficient concentration of available Cu and Zn is favoured by acidic reaction of soil (Nayak *et al.*, 2000). Moreover, organic matter content in soil form soluble complexes with Cu and Zn and increase their availability (Kavitha *et al*., 2019).

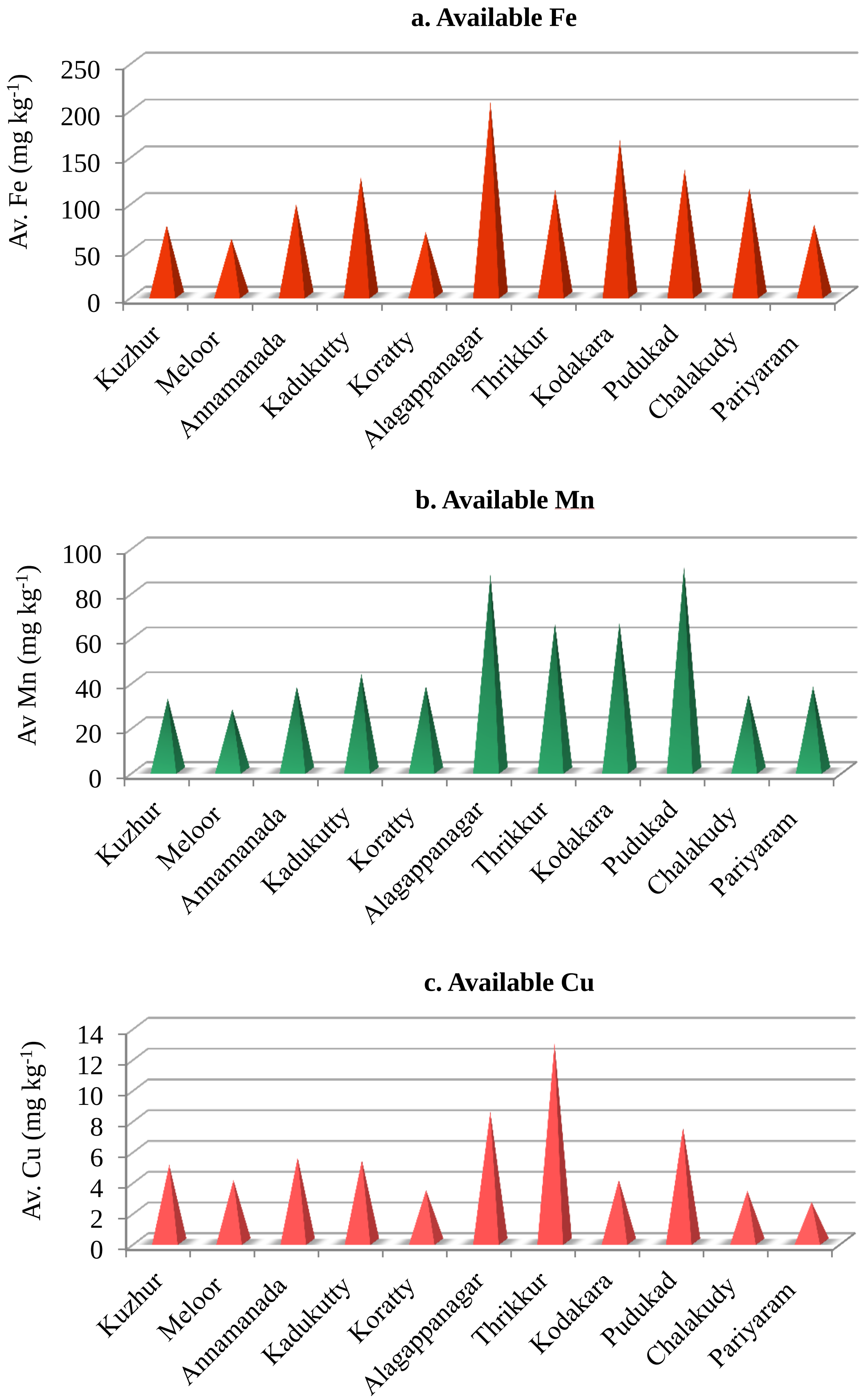
5.3.11. Available boron (Av.B)

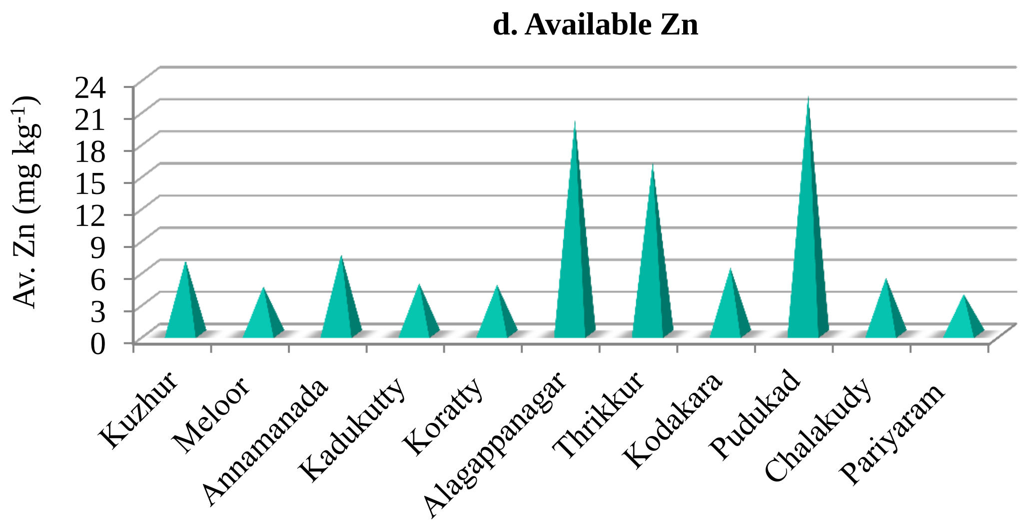
Available boron was deficient (<0.5 mg kg^{-1}) in seventy nine per cent of the samples (Fig 5.7f). The concentration ranged from 0.01 to 1.91 mg kg^{-1} soil. The average content was less than 0.50 mg kg^{-1} in all *panchayats* except Kadukutty and Thrikkur. The highest mean content of 1.21 mg kg^{-1} was observed in Kadukutty and the lowest mean value of 0.04 mg kg^{-1} was noted in Alagappanagar (Fig 5.8e). The lateritic soils formed from igneous parent material (Ollier and Rajaguru, 1989) are poor in B content (Barman *et al.*, 2017). The availability of B is highly pH dependent and is generally low in acid soils of high rainfall areas (Tsadilas and Kassioti, 2005). Though, acid soils support increased solubility and availability of boron, the nutrient is lost through leaching causing widespread deficiency (Kavitha *et al*., 2019).

5.3.12. Exchange acidity

Exchange acidity is contributed by the exchangeable Al^{3+} and H^{+} ions on the adsorption sites of soil. The variation in soil exchange acidity ranged from 0.03 to 1.27 cmol kg^{-1}. The minimum mean value of 0.04 cmol kg^{-1} was observed in Koratty and Alagappanagar while the maximum average value of 0.18 cmol kg^{-1} was observed in Meloor (Fig 5.9). Seventy four per cent samples had an exchange acidity less than 0.10 cmol kg^{-1} soil, indicating lower content of adsorbed Al^{3+} and H^{+} ions. Increased exchange acidity is characteristic of soils in which acidification processes are advanced and pH values are lower than 5.0 (Rengel, 2004). In the present study only twenty three per cent samples were very strongly to extremely acidic with pH values below 5.00.

Fig 5.8. Mean values of micro nutrients in different *panchayats*





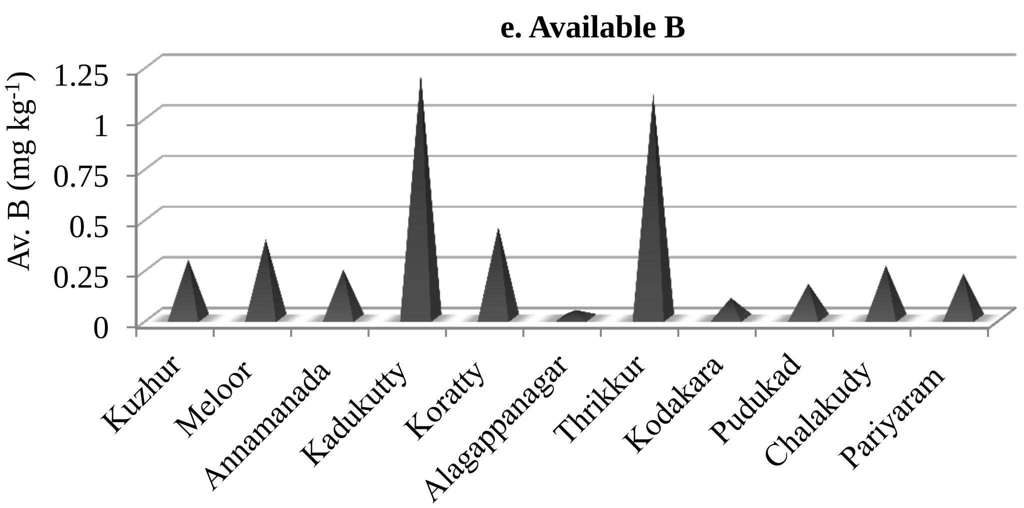
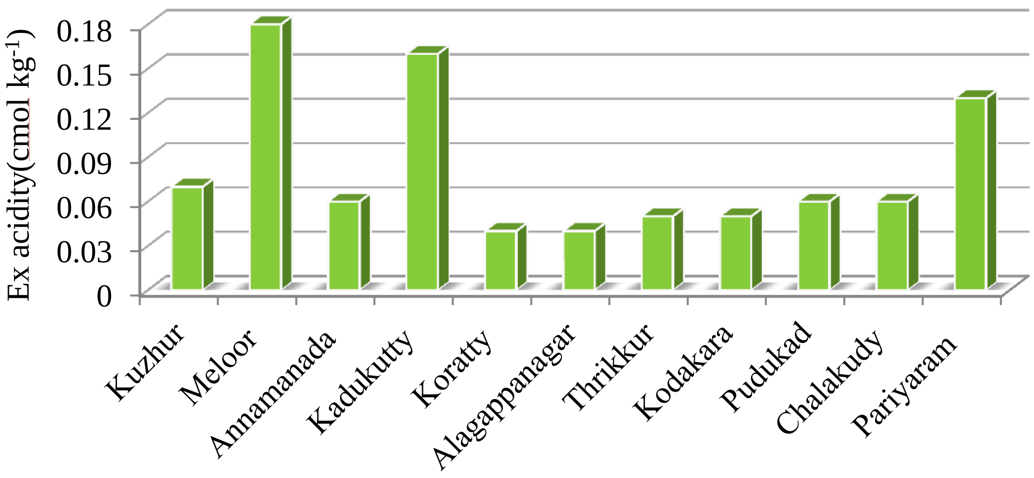


Fig 5.9. Mean values of exchange acidity in different *panchayats*



5.4. Biological attributes

5.4.1. Organic carbon (OC)

Organic carbon content in soil is an index of soil fertility as it influences the microbial activity and biological transformations of nutrients in soil. The organic carbon content ranged from 0.40 to 3.75 per cent and it was high (>1.50%) in 29 per cent and medium (0.75-1.5%) in 57 per cent of the samples (Fig 5.11a). The highest mean value of organic carbon was in Annamanada (3.75%) and lowest in Pariyaram (1.91%) (Fig 5.10a). The average OC content was found greater than 0.75 per cent in all *panchayats*. Organic carbon content in these soils was reported to be medium to high by Venugopal *et al.*, (2019) in the pre flood scenario. Further accumulation of organic debris would also have contributed to higher content of organic carbon.

5.4.2. Dehydrogenase activity (DHA)

Dehydrogenase is a respiratory enzyme and is considered as an indicator of oxidative metabolism in soil. Dehydrogenase activity (DHA) in the samples ranged from 1.02 to 535.00 µg TPF g^{-1} $24h^{-1}$. All the *panchayats* except Meloor, Kadukutty and Koratty exhibited an average activity of >30 µg TPF g^{-1} $24h^{-1}$ (Fig 5.10b). The lowest activity of 21.89 µg TPF g^{-1} $24h^{-1}$ was observed in Koratty and the highest of 73.66 µg TPF g^{-1} $24h^{-1}$ in Pudukkad. Wolinska and Stepniewska (2012) reported that, dehydrogenase activity is more in anaerobic rather than aerobic soil when assayed using TTC. The lower activity might also be due to the acidic reaction of soil which restricts microbial activity (Aoyama and Nagumo, 1996).

5.4.3. Microbial biomass carbon (MBC)

Microbial biomass is the living part of soil organic matter and microbial biomass carbon is the measure of carbon assimilated within the body of soil microbes. MBC analysed by chloroform fumigation extraction method varied between 24.99 and 1793.19 µg g^{-1}. The MBC content in forty five per cent of the samples was low ranging from 100 and 300 µg g^{-1}, medium (300-400 µg g^{-1}) in sixteen per cent of the samples and high (>400μg g^{-1}) in seventeen per cent of the samples (Fig 5.11b). Alagappanagar recorded the highest average MBC content of 508.72 µg g^{-1} soil. All the other *panchayats* had an average content between 100 and 400 µg g^{-1} soil (Fig 5.10c). Anaerobic environment caused by flooding as well as soil acidity would have restricted the activity of soil microbes (Unger *et al*., 2009) and resulted in low content of MBC.

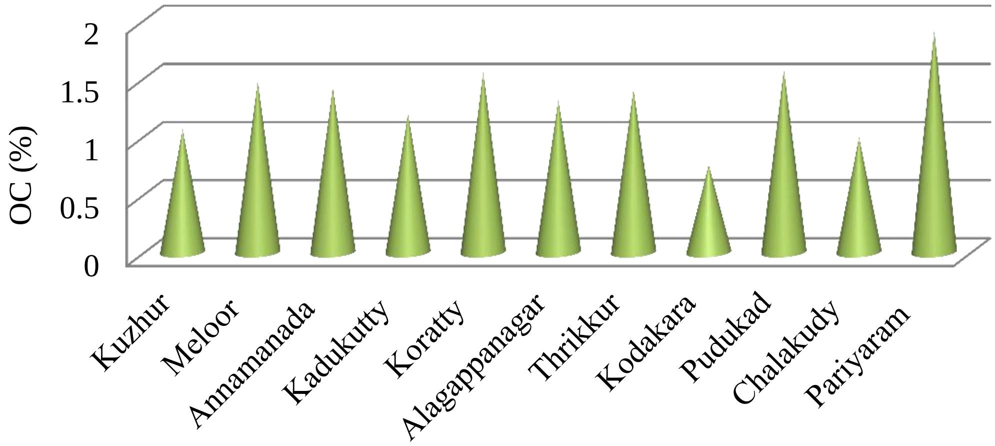
5.5. Correlation between soil characteristics

The physical parameters of soil was found to have strong correlation with organic carbon content in soil (Table 4.7). Soil organic carbon was found to have a significant negative correlation with bulk density and particle density and positive correlation with porosity, moisture content, water holding capacity and aggregate stability. Organic colloids act as a binding agent to form stable aggregates and hence increase soil porosity (Idowu, 2003). As soil pores increase soil volume and decrease its mass, a significant negative correlation was observed between porosity and bulk density.

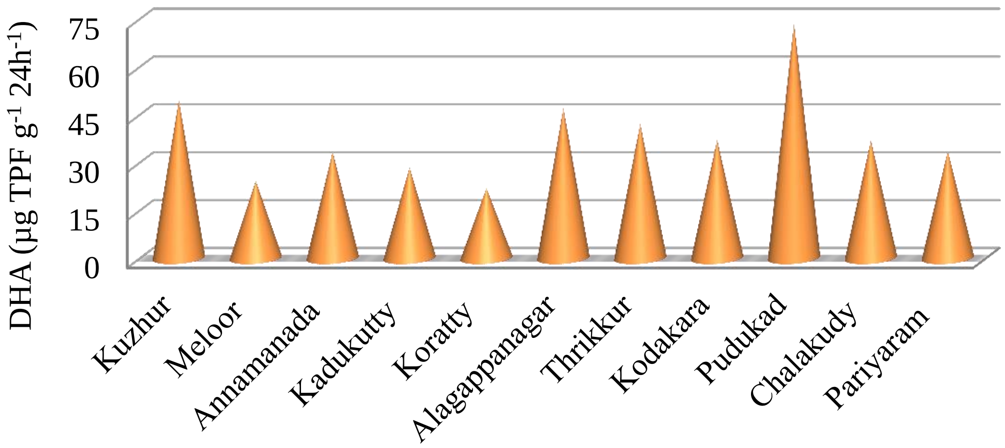
Organic carbon was positively correlated with available nitrogen content as the mineralization of nitrogen depends on the ratio of carbon to nitrogen (C:N) in soil (Vanilarasu and Balakrishnamurthy, 2014). Available magnesium was seen to have positive correlation with available potassium, calcium, sulphur and organic carbon. Sulphur was positively correlated with electrical conductivity as sulphates has an influence in increasing soil acidity which enhance dissolution of bases leading to increase in soluble salts (Cifuentes and Lindemann, 1993). The significant negative correlation of exchange acidity with pH and available calcium shows that as pH decreases aluminium replaces calcium from the soil exchange sites. Similar finding was also reported by Bhindhu (2017).

Fig 5.10. Mean values of soil biological attributes in different *panchayats*

a. Organic carbon



b. Dehydrogenase activity



c. Microbial biomass carbon

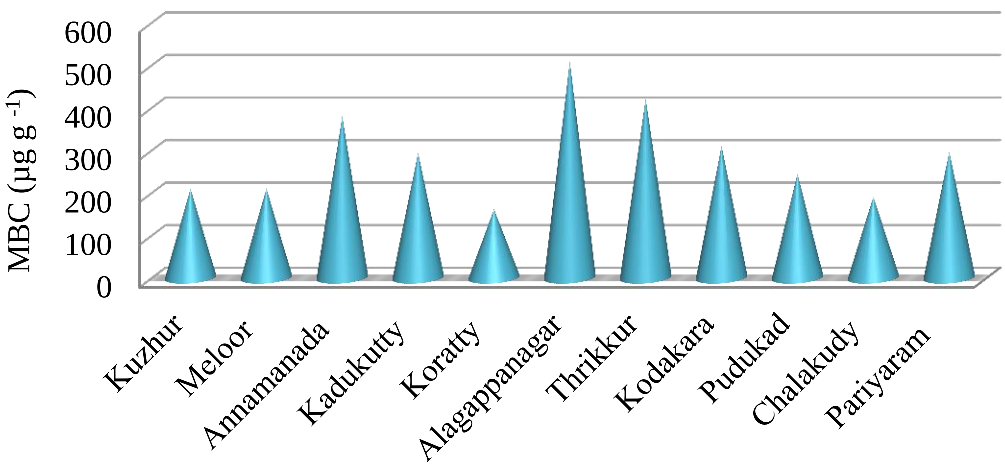
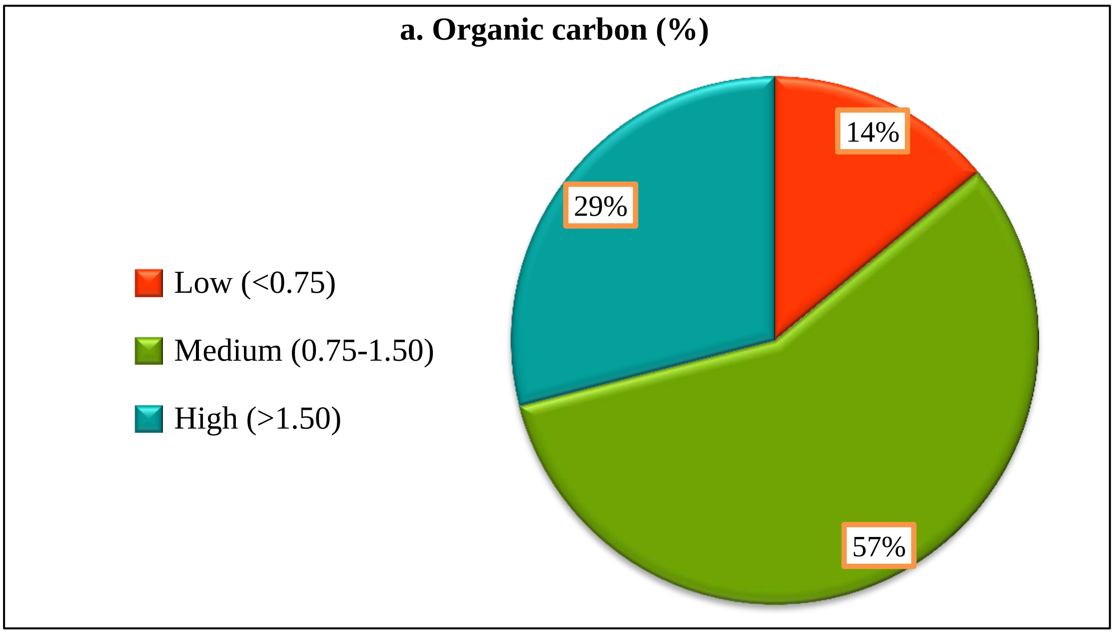
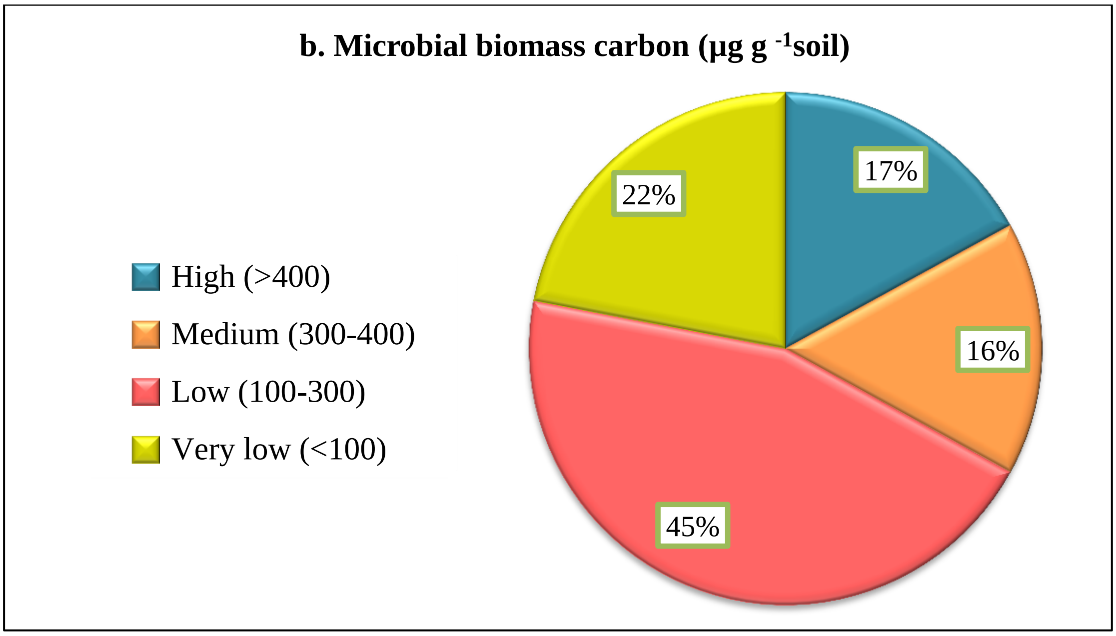


Fig 5.11. Frequency distribution of biological attributes in different classes





5.6 Nutrient Index

Nutrient Index (N.I) value is a measure of nutrient supplying capacity of soil to plants (Singh *et al*., 2016). This index is used to evaluate the fertility status of soils based on the samples in each of the three classes, *i.e*., low, medium and high. Nutrient Index of available nitrogen, phosphorus and potassium was computed for the flood affected soils of AEU 10 in Thrissur District. The nutrient index of available nitrogen was found to be low (1.49). This might be because fifty three per cent samples were diagnosed to be low with respect to available nitrogen. The nutrient index of available phosphorus and potassium was 3 and 2.63 respectively. Hence, among the primary nutrients, nitrogen deficiency is the major constraint to soil quality.

5.7. Soil Quality Index

The soil quality index was obtained by adding all the weighed MDS variable scores. In non-linear scoring method, mean SQI ranged between 0.50 and 0.70 in all *panchayats*. It was highest in Pariyaram (0.68) and the lowest was in Meloor (0.55) (Table 4.14). Among the eight MDS parameters, bulk density had the highest contribution to SQI in Meloor (29.05%), Kadukutty (22.35%), Koratty (23.67%), Chalakudy (22.11%) and Pariyaram (24.36%), whereas the contribution of pH was maximum in Kuzhur (24.12%), Annamanada (22.44%), Alagappanagar (27.51%), Thrikkur (28.29%), Kodakara (24.52%) and Pudukad (27.50%). Available nitrogen had the lowest contribution to SQI in Meloor (2.97%) and MBC in Koratty (3.50%) and Thrikkur (1.95%). Available boron was found to have the lowest contribution in all other *panchayats* (Fig 5.12a).

In linear method of scoring, the highest mean SQI was observed in Thrikkur (0.87) and lowest (0.71) in Meloor. All the *panchayats* had a mean SQI value >0.70. Soil pH had the highest contribution to SQI in Meloor (28.93%), Alagappanagar (31.05%) and Pudukad (32.53%) while, available calcium had the highest contribution in all other *panchayats* (Fig 5.12b). Available boron had the lowest contribution to SQI in Annamanada, Alagappanagar, Pudukkad and Pariyaram and MBC in all other *panchayats*.

The radar diagram (Fig 5.13) explicates the mean SQI values of different *panchayats* computed by non-linear and linear methods of scoring. A significant positive correlation (0.79**) was found between the Soil Quality Index computed by the two methods (Fig 5.14)**.**

5.8. Relative Soil Quality Index

Relative Soil Quality Index indicates the deviation of SQI from the maximum achievable value and is rated as poor (<50%), medium (50-70%) and good (>70%) (Karlen and Stott, 1994). The RSQI was poor in thirteen locations as per both the scoring methods, medium in eighty two locations as per non-linear scoring (Fig 5.16a) and eighty six locations as per linear scoring (Fig 5.16b) method. The mean values of RSQI in all *panchayats* of the study area ranged from 50-70 per cent and is rated as medium (Table 4.15 and Fig 5.15).

Bulk density, soil pH, and available calcium were the major drivers of SQI in the flood affected soils of AEU 10 in Thrissur district. The importance of these parameters can be attributed to their role in regulating various functions in soil that are important from the perspective of soil fertility and crop productivity. Alternative management strategies to optimize available nitrogen, boron, and microbial biomass carbon content in soil have to be adopted to enhance the overall Relative Soil Quality Index.

Fig 5.12. Contribution of different parameters to soil quality index

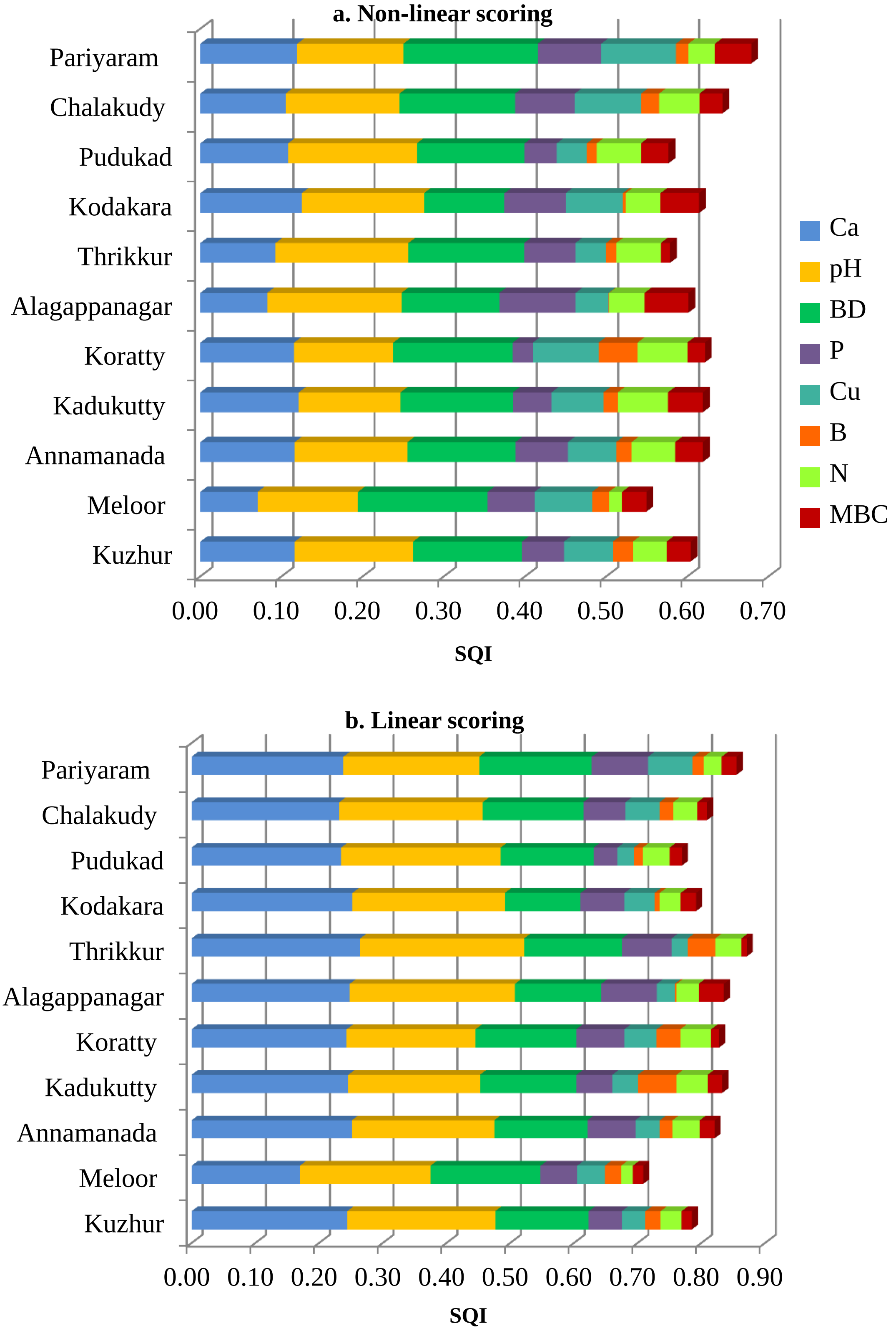


Fig 5.13. Radar diagram explicating SQI in non-linear and linear method

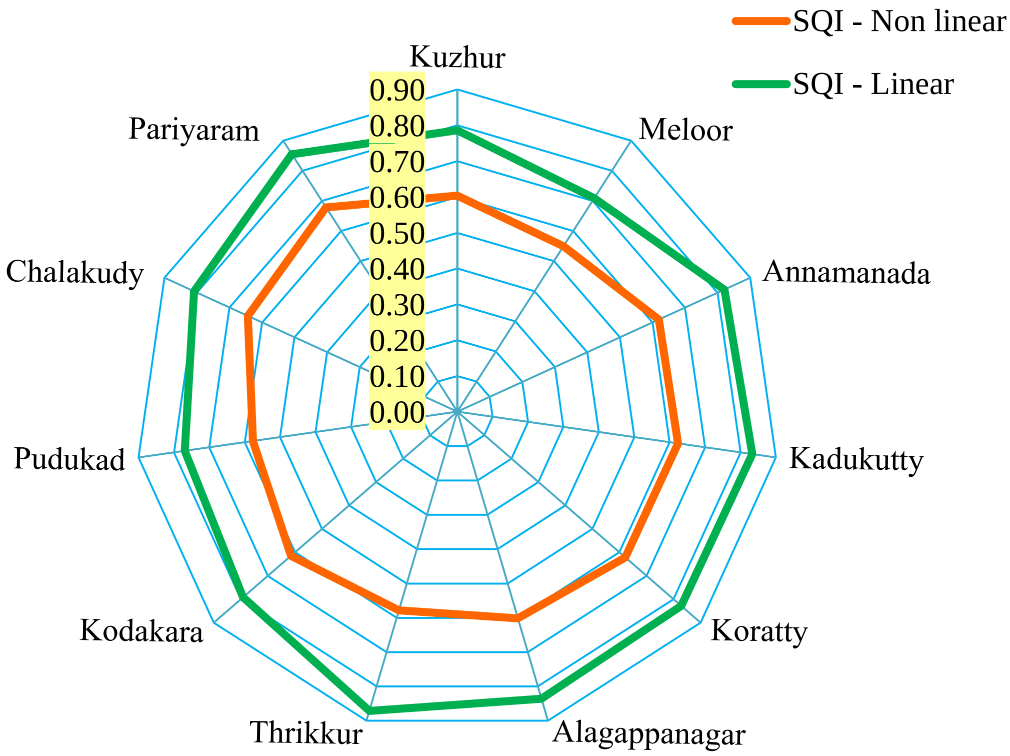


Fig 5.14. Correlation between non-linear and linear method of SQI

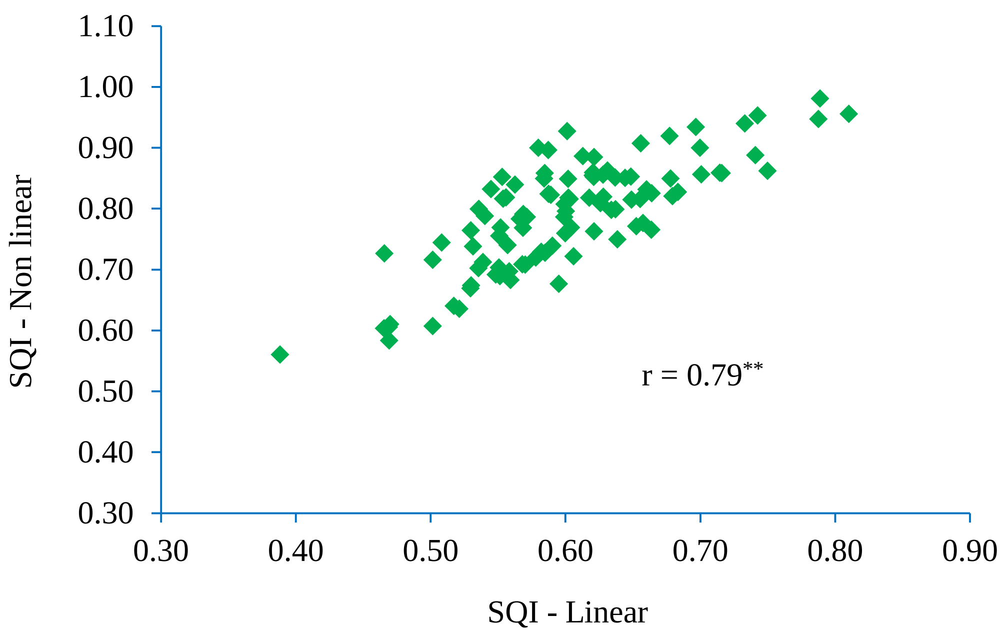


Fig 5.15. Mean RSQI in different *panchayats*

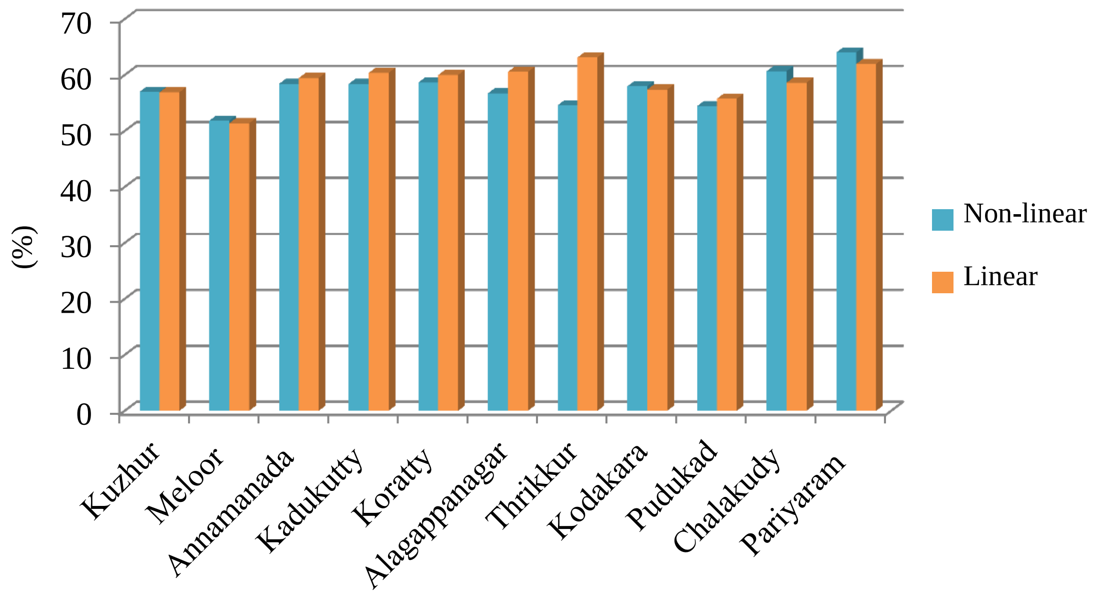
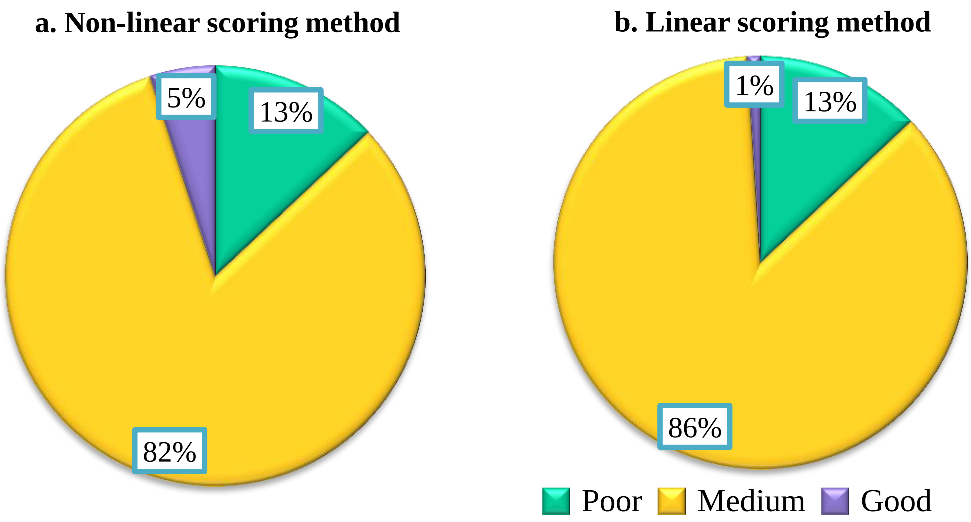


Fig 5.16. Frequency distribution of RSQI classes



Summary

6. SUMMARY

The Agro-ecological unit (AEU 10) designated as North Central Laterites represents midland laterite terrain covering an area of 1,71,469 ha (4.41%) in the state of Kerala. The soils of the warm, humid tropical region are strongly to moderately acidic, gravelly, poor in silica, and often underlain by plinthite at various depths. Excessive rainfall continuously leaches basic cations from surface soil and accumulates oxides of iron and aluminium in the solum, which gives a characteristics reddish colour to the soil. High temperature accelerates the oxidation of organic matter leading to low humus content in soil which reflects in the poor yield of prevalent crops.

Soil quality concept has been adopted as a technical framework for grading and evaluating management effect. Under extreme environmental conditions, dynamic soil properties including physical, chemical and biological characteristics, which mostly influence soil quality change significantly. The deluge in August, 2018 had caused great change to the soil environment in the state of Kerala. Drastic changes in soil fertility and productivity posing a threat to crop production has been evidenced. The removal of nutrient rich upper layer from upstream regions and deposition of sediments in downstream region caused redistribution of functional plant nutrients. There was an urgent need to analyse the revised fertility status in order to restore soil health and sustain productivity

The present study entitled "Assessment of soil quality in the post flood scenario of North Central Laterites (AEU 10) in Thrissur District of Kerala and mapping using GIS techniques" was undertaken to evaluate the altered status of soil fertility in the flood affected areas. One hundred geo-referenced composite soil samples (0-20 cm) from the worst affected locations comprising 11 *grama panchayats* were collected. The samples were analysed for 23 soil quality parameters namely bulk density (BD), particle density (PD), porosity, max WHC, moisture content, aggregate stability (MWD), soil pH, electrical conductivity (EC), available N, available P, available K, available Ca, available Mg, available S, available Fe, available Mn, available Cu, available Zn, available B, exchangeable acidity, organic carbon (OC), dehydrogenase activity (DHA) and microbial biomass carbon (MBC). The analytical values of physical, chemical and biological characteristics of soil samples were categorized as per standard ratings and variations in mean values of different *panchayats* were compared. Correlation study was conducted to understand the strength of relationship between the parameters. Nutrient Index which is a measure of nutrient supplying capacity of soil was worked out for primary nutrients. Principal component analysis (PCA) was used as the statistical tool to produce minimum data set (MDS) and to formulate soil quality index (SQI). Further, the deviation in soil quality was measured and expressed in terms of relative soil quality index (RSQI).

Geo-referenced thematic maps of important soil parameters and relative soil quality index (RSQI) of the flood affected *panchayats* in AEU 10 of Thrissur district were prepared with IDW spatial analyst tool using ArcGIS software.

The noticeable conclusions of the study are summarized below

- Bulk density of soil ranged from 0.67 to 1.64 Mg m^{-3} and was found to be less than 1.40 Mg m^{-3} in eighty one per cent of the samples.
- Soil porosity was medium (30-50%) in ninety six per cent samples.
- Water Holding Capacity of all the samples was in medium range (20-50%).
- Gravimetric soil moisture content varied between 10 and 58.16 per cent.
- Mean Weight Diameter indicating aggregate stability of the particles ranged from 0.63 to 5.39 mm.
- Ninety two per cent of samples recorded pH below 6.5 and forty seven per cent had pH below 5.5.
- Fifty three per cent samples were low (<280 kg ha^{-1}) in available nitrogen.
- Available phosphorus content was very high and ranged from 48.00 to 851.79 kg ha^{-1}
- Ninety seven per cent samples were medium to high (>116 kg ha^{-1}) in available potassium.
- Available calcium was sufficient (>300 mg kg^{-1}) in ninety seven per cent samples.

- Deficiency of available magnesium (<120 mg kg^{-1}) was recorded in 67 per cent samples.
- Available sulphur status was sufficient (>5 mg kg^{-1}) in all samples.
- All samples were sufficient with respect to available iron (>5 mg kg^{-1}) and manganese (>1 mg kg^{-1}).
- Deficiency of available copper and zinc was negligible.
- Available boron was found to be deficient (<0.5 mg kg^{-1}) in the case of 79 per cent of the samples.
- The value of exchange acidity ranged from 0.03 to 1.27 cmol kg^{-1} soil with a mean value of 0.1 cmol kg^{-1}.
- Organic carbon content in the samples varied from 0.40 to 3.75 per cent and was high (>1.50%) in 29 per cent of the samples, and medium (0.75-1.5%) in 57 per cent of the samples.
- Dehydrogenase enzyme activity (DHA) in the soil samples ranged from 1.02 to 535.00 µg TPF g^{-1} $24h^{-1}$.
- Microbial biomass carbon (MBC) was less than 300 µg g^{-1} in 45 per cent of the samples indicating low activity of microbes.
- Soil organic carbon was found to have a strong negative correlation with bulk density and particle density and significant positive correlation with porosity, water holding capacity, moisture content, aggregate stability of the soil particles and available nitrogen content.
- Available magnesium was found to have significant positive correlation with available calcium, potassium, sulphur and organic carbon content in the soil.
- The significant negative correlation of exchange acidity with pH and available calcium shows that as pH decreases aluminium replaces calcium from the soil exchange sites.
- The nutrient index (NI) of available nitrogen was found to be low (1.49); whereas, it was high in case of available phosphorus (3.00) and potassium (2.63).

- Soil bulk density, soil pH, available nitrogen, available phosphorus, available calcium, available copper, available boron, and microbial biomass carbon were identified as key indicators of soil quality in the minimum data set.
- Soil pH, available nitrogen and microbial biomass carbon were scored as ‘more is better’ function; bulk density, available copper were scored as ‘less is better’ function and available calcium, phosphorus and boron were scored as ‘optimum is better’ function based on their contribution to soil quality.
- Mean soil quality index (SQI) of different *panchayats* ranged from 0.50 to 0.70 and from 0.71 to 0.87 as per non-linear and linear scoring methods respectively.
- Soil quality index computed by non-linear and linear scoring methods had significant positive correlation (0.79^{**}).
- Contribution of soil parameters to SQI followed the order
  pH = BD > Ca > P = Cu > N > MBC > B.
- The relative soil quality index (RSQI) was poor in thirteen locations as per both the scoring methods and medium in eighty two locations as per non-linear scoring and eighty six locations as per linear scoring method.
- The mean relative soil quality index of the flood affected *panchayats* in AEU 10 of Thrissur District was medium (50-70%) in status.
- Decline in SQI is due to the shifting of key indicators from the optimal range.
- Site specific soil management practices to optimize quality indicators can improve soil fertility and enhance productivity.

References

REFERENCES

Akpoveta, V. O., Osakwe, S. A., Ize-Iyamu, O. K., Medjor, W. O., and Egharevba, F. 2014. Post flooding effect on soil quality in Nigeria: the Asaba, Onitsha experience. *Open J. Soil Sci.* 4: 72-80.

Anderson, T. H. 2003. Microbial eco-physiological indicators to assess soil quality. *Agric. Ecosyst. Environ*. 98: 285-293.

Andrews, S. S., Karlen, D. L., and Mitchell, J. P. 2002. A comparison of soil quality indexing methods for vegetable systems in Northern California. *Agric. Ecosyst. Environ.* 90: 25-45.

Andrews, S. S., Mitchell, J. P., Mancinelli, R., Karlen, D. L., Hartz, T. K., Horwath, W. R., Pettygrove, G. S., Scow, K. M., and Munk, D. S. 2002. On-farm assessment of soil quality in California's Central Valley. *Agron. J.* 94: 12-23.

Aoyama, M. and Nagumo, T. 1996. Factors affecting microbial biomass and dehydrogenase activity in apple orchard soils with heavy metal accumulation. *Soil Sci. Plant Nutr.* 42 (4): 821-831.

Arshad, M. A. and Coen, G. M. 1992. Characterization of soil quality: physical and chemical criteria. *Am. J. Altern. Agric*. 7: 25-31.

Arshad, M. A., Lowery, B., and Grossman, B. 1996. Physical tests for monitoring soil quality. In: Doran, J. W. and Jones, A. J. (eds.), *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publications, Madison, pp. 123-141.

Asadi, A., Bujang B. K. H., Hanafi, M. M., Mohamed, T. A., and Shariatmadari, N. 2009. Role of organic matter on electro-osmotic properties and ionic modification of organic soils. *Geosci. J.* 13: 175-181.

Barman, P., Sen, A., Phonglosa, A., and Bhattacharyya, K. 2017. Depth wise distribution of boron in some soils of Red and Laterite zone of West Bengal, India. *Int. J. Curr. Microbiol. Appl. Sci.* 6(12): 4126-4137.

Bastida, F., Zsolnay, A., Hernandez, T., and Garcia, C. 2008. Past, present and future of soil quality indices: a biological perspective. *Geoderma* 147: 159-171.

Becker, M. and Asch, F. 2005. Iron toxicity in rice-conditions and management concepts. *J. Plant Nutr. Soil Sci.* 168(4): 558-573.

Berger, K. C. and Truog, E. 1939. Boron determination in soils and plants. *Indian Eng. Chem. Anal. Ed.* 11: 540-542.

Bhindhu, P. S. 2017. Chemistry and transformations of calcium and magnesium in tropical acid soils of Kerala. Ph.D.(Ag) thesis, Kerala Agricultural University, Thrissur, 283p.

Bossio, D. A. and Scow, K. M. 1998. Impacts of carbon and flooding on soil microbial communities: phospholipid fatty acid profiles and substrate utilization patterns. *Microb. Ecol.* 35: 265-278.

Bray, R. H. and Kurtz, L. T. 1945. Determining total, organic and available forms of phosphate in soils. *Soil Sci.* 59: 39-45.

Brejda, J. J., Karlen, D. L., Smith, J. L., and Allan, D. L. 2000. Identification of regional soil quality factors and indicators in Northern Mississippi loess hills and Palouse Prairie. *Soil Sci. Soc. Am. J.* 64: 2125-2135.

Brzezinaska M., Stepniewska, Z., and Stepniewski, W. 1998. Soil oxygen status and dehydrogenase activity. *Soil Biol. Biochem.* 30(13): 1783-1790.

Buresh, R. J., Reddy, K. R., and Van Kessel, C. 2008. Properties of submerged soils. In: Schepers, J. S. and Raun, W. R. (eds.), *Nitrogen in Agricultural Systems*. American Society of Agronomy, Madison, WI, pp. 401-436.

Casida, L. E., Klein, D. A., and Santoro, T. 1964. Soil dehydrogenase activity. *Soil Sci.* 98: 371-376.

Chaudhari, P. R., Ahire, D. V., Chkravarty, M., and Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *Int. J. Sci. Res. Publ.* 3(2): 1-8.

Cifuentes, F. R. and Lindemann, W. C. 1993. Organic matter stimulation of elemental sulfur oxidation in a calcareous soil. *Soil Sci. Soc. Am. J.* 57: 727-731.

Das, D. K. 2013. *Introductory Soil Science.* Kalyani Publishers, Ludhiana, 645p.

Das, S., Bhattacharyya, P., and Adhya, T. K. 2011. Impact of elevated CO2, flooding, and temperature interaction on heterotrophic nitrogen fixation in tropical rice soils. *Biol. Fertil. Soils* 47: 25-30.

De-Campos, A. B., Mamedov, A. I., and Chi-hua, H. 2009. Short-term reducing conditions decrease soil aggregation. *Soil Sci. Soc. Am. J.* 73(2): 550-559.

DoADFW [Department of Agriculture Development and Farmers Welfare]. 2018. *Soil Fertility Handbook.* Department of Agriculture Development and Farmers Welfare, Govt. of Kerala, Thiruvananthapuram, 256p.

DSSSC [Department of Soil Survey and Soil Conservation]. 2018. *Soil Health Status of Kerala in the Post Flood Scenario.* Department of Soil Survey and Soil Conservation, Govt. of Kerala, Thiruvananthapuram, pp. 150-204.

Elhottova, D., Kristufek, V., Triska, J., Chrastny, V., Uhlirova, E., Kalcik, J., and Picek T. 2005. Immediate impact of the flood (Bohemia, August 2002) on selected soil characteristics. *Water Air Soil Pollut.* 173: 177-193.

Eulenstein, F., Muller, L., and Helming, K. 1998. Odra 1997 flood effects on soil properties of cultivated areas in Germany. *Int. Agrophysics* 12: 241-247.

Evans, H. J. and Barber, L. E. 1977. Biological nitrogen fixation for food and fiber production. *Sci.* 197: 332-339.

Fageria, N. K. 2009. *The Use of Nutrients in Crop Plants.* CRC Press, Taylor and Francis Group, London, 430p.

Fageria, N. K., Carvalho, G. D., Santos, A. B., Ferreira, E. P. B., and Knupp, A. M. 2011. Chemistry of lowland rice soils and nutrient availability. *Comm. Soil Sci. Plant Anal.* 42:1913–1933.

Fageria, N. K., Santos, A. B., Filho, M. P. B., and Guimaraes, C. M. 2008. Iron toxicity in lowland rice. *J. Plant Nutr.* 31: 1676-1697.

Ferronato, C., Marinari, S., Francioso, O., Bello, D., Trasar-Cepeda, C., and Antisari, L. V. 2019. Effect of waterlogging on soil biochemical properties and organic matter quality in different salt marsh systems. *Geoderma* 338: 302-312.

Filip, J. 2002. International approach to assessing soil quality by ecologically-related biological parameters. *Agric. Ecosyst. Environ*. 88(2): 169-174.

Fitter, A. H. and Hay, R. K. M. 2012. *Environmental Physiology of Plants* (6th Ed.). Academic Press, London, 367p.

Gasparatos, D., Massas, I., and Godelitsas, A. 2019. Fe-Mn concretions and nodules formation in redoximorphic soils and their role on soil phosphorus dynamics: current knowledge and gaps. *Catena* 182: 1-12.

Geetha, P. 2008. Quantity-intensity relations of phosphorus with reference to its bioavailability in lateritic soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Thrissur, 111p.

Gelsomino, A., Badalucco, L., Ambrosoli, R., Crecchio, C., Puglisi, E., and Meli, S. M. 2006. Changes in chemical and biological soil properties as induced by anthropogenic disturbance: a case study of an agricultural soil under recurrent flooding by wastewaters. *Soil Biol. Biochem.* 38: 2069-2080.

Gonzalez Mace, O., Steinauer, K., Jousset, A., Eisenhauer, N., and Scheu, S. 2016. Flood induced changes in soil microbial functions as modified by plant diversity. *PLoS ONE.* 11: 1-15. Available: https://doi.org/10.1371/journal.pone.0166349. [02 Feb, 2020].

Gupta, U. C. 1972. Effects of boron and limestone on cereal yields and on B and N concentrations of plant tissue. *Commun. Soil Sci. Plant Anal.* 6: 439-450.

Hanway, J. J. and Heidel, H. 1952. Soil analysis methods as used in Iowa state college soil testing laboratory. *Iowa Agric.* 57: 1-31.

Hayashi, K., Nishimura, S., and Yagi, K. 2006. Ammonia volatilization from the surface of a Japanese paddy field during rice cultivation. *Soil Sci. Plant Nutr.* 52(4): 545-555.

Hilscherova, K., Dusek, L., Kubik, V., Cupr, V., Hofman, J., Klanova, J., and Holoubek, I. 2007. Redistribution of organic pollutants in river sediments and alluvial soils related to major floods. *J. Soils Sedim.* 7(4): 167-177.

Idowu, O. J. 2003. Relationships between aggregate stability and selected soil properties in humid tropical environment. *Commun. Soil Sci. Plant Anal.* 34: 695-708.

IRRI [International Rice Research Institute]. 1967. *Annual Report for 1966*. International Rice Research Institute, Los Banos, Philippines, 82p.

Jackson, M. L. 1958. *Soil Chemical Analysis* (Indian Reprint, 1967). Prentice Hall of India Private Limited, New Delhi, 498p.

Jenkinson, D. S. and Pawlson, D. S. 1976. The effect of biocidal treatments on metabolism in soil- method for measuring soil biomass. *Soil Biol. Biochem.* 8: 209-213.

Kalshetty, B. M., Giraddi, T. P., Sheth, R. C., and Kalashetti, M. B. 2012. River Krishna flood effects on soil properties of cultivated areas in Bagalkot district, Karnataka state. *Glob. J. Inc.* 12(6): 23-28.

Karlen, D. L. and Stott, D. E. 1994. A framework for evaluating physical and chemical indicators of soil quality. *Soil Sci. Soc. Am. Spec. Publ*. 35: 53-72.

Karlen, D. L., Andrews, S. S., and Doran, J. W. 2001. Soil quality: current concepts and applications. *Adv. Agron.* 74: 1-40.

Kashem, M. A. and Singh, B. R. 2001. Metal availability in contaminated soils: I. effects of flooding and organic matter on changes in Eh, pH and solubility of Cd, Ni and Zn. *Nutr. Cycl. Agroecosyst*. 61: 247–255.

KAU [Kerala Agricultural University]. 2018. *Regional soil health management-soil resource management and biological soil fertility*. Kerala Agricultural University, Thrissur, 53p.

Kavitha, C. and Sujatha, M. P. 2015. Evaluation of soil fertility status in various ecosystems of Thrissur District, Kerala, India. *Int. J. Agric. Crop. Sci.* 8: 328-338.

Kavitha, C., Sujatha, M. P., and Tata, R. 2019. Spatial variations in soil micronutrients as influenced by agro ecological conditions in a tropical humid region. *Trop. Ecol*. 37: 1-17.

Keen, B. A. and Raczkowski, H. 1921. The relation between the clay content of certain physical properties of soil. *J. Agric. Sci.* 11(4): 441-449.

Khazaei, A., Mosaddeghi, M. R., and Mahboubi, A. A. 2008. Impacts of test conditions, soil organic matter, clay and calcium carbonate contents on mean weight diameter and tensile strength of aggregates of some Hamedan soils. *J. Water Soil Sci.* 12(44): 123-134.

Kogel-Knabner, I., Amelung, W., Cao, Z., Fiedler, S., Frenzel, P., Jahn, R., Kalbitz, K., Kolbl, A., and Schloter, M. 2010. Biogeochemistry of paddy soils. *Geoderma* 157: 1-14.

Konsten, C. J. M., Nico van, B., Suping, S., Aribawa, I. B., and Groenenberg, J. E. 1994. Effects of flooding on pH of rice-producing, acid sulfate soils in Indonesia. *Soil Sci. Soc. Am. J.* 58: 871-88.

Kreuzwieser, J. and Rennenberg, H. 2014. Molecular and physiological responses of trees to waterlogging stress. *Plant Cell Environ.* 37(10): 2245-2259.

Kundu, S., Vassanda, C. M., Saha, J. K., Rajendiran S., Hati, K. M., Biswas, A. K., Reddy , K. S., and Subba Rao, A. 2012. Assessing soil health of Vertisol of AESR 10.1 using selected physical, chemical and biological attributes of soils. *J. Indian Soc. Soil Sci.* 60: 281-287.

Lal, R. 1991. Soil structure and sustainability. *J. Sustain. Agric.* 1(4): 67-92.

Larson, W. E. and Pierce, F. J. 1991. Conservation and enhancement of soil quality. In: Dumanski, J. E., Latham, P. M., and Myers, R. (eds.), *Evaluation for sustainable land management in the developing world Vol-2: technical papers.* Proceedings of the International workshop, 15-21 Sept. 1991. Chiang Rai, Thailand, pp. 175-203.

Lee, S. B., Lee, C. H., Jung, K. Y., Park, K. D., Lee, D., and Kim, P. J. 2009. Changes of soil organic carbon and its fractions in relation to soil physical properties in a long-term fertilized paddy. *Soil Tillage Res.* 104: 227-232.

Liebig, M. A., Varvel, G., and Doran, J. W. 2001. A simple performance-based index for assessing multiple agroecosystem functions. *Agron. J.* 93: 313-318.

Maliszewska-Kordybach, B., Klimkowicz-Pawlas A., Smreczak, B., and Galazka, R. 2011. Effect of flooding on contamination of agricultural soils with metals and PAHs: the Middle Vistula gap case study. *Water Air Soil Pollut*. 223: 687-697.

Massoumi, J. and Cornfield, A. H. 1963. A rapid method for determination sulphate in water extracts of soils. *Anal.* 88: 321-322.

Mausel, P. W. 1971. Soil quality in Illinois-an example of a soils geography resource analysis. *Prof. Geographer* 23: 127-136.

Mayland, H. M. and Wilkinson, S. R. 1989. Soil factors affecting magnesium availability in plant-animal systems: a review. *J. Anim. Sci.* 67: 3437-3444.

Motsara, M. R., Singh, J., and Verma, K. P. S. 1982. Nutrient indexing system in soil fertility evaluation and fertilizer use in India. *Fertil. News* 27(9): 92-99.

Murphy, J. and Riley, J. P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta* 27: 31-36.

Nair, K. M., Kumar, K. S., Anil, K. P., Naidu L. G. K., and Sarkar, D. 2011.Variability of lateritic soil development in humid tropical environment. *Indian J. Agric. Res*. 30(2): 12-20.

Navas, M., Benito, M., Rodriguez, I., and Masaguer, A. 2011. Effect of five forage legume covers on soil quality at the eastern plains of Venezuela. *Appl. Soil Ecol.* 49: 242-249.

Nayak, D. C., Mukhopadhyay, S., and Sarkar, D. 2000. Distribution of some available micronutrients in alluvial soils of Aurunachal Pradesh in relation to soil characteristics. *J. Indian Soc. Soil Sci.* 48(3): 612-614.

Nortcliff, S. 2002. Standardisation of soil quality attributes. *Agric. Ecosyst. Environ*. 88: 161-168.

Ollier, C. and Rajaguru, S. N. 1989. Laterite of Kerala (India). *Geogr. Fis. Dinam. Quat*. 12: 27-33.

Oorts, K., Vanlauwe, B., and Merckx, R. 2003. Cation exchange capacities of soil organic matter fractions in a ferriclixisol with different organic matter inputs. *Agric. Ecosyst. Environ*. 100(3): 161-171.

Pal, S. K. 2013. *Soil Sampling and Methods of Analysis.* New India Publishing Agency, New Delhi, 315p.

Parent, C., Capelli, N., Berger, A., Crevecoeur, M., and Dat J. F. 2008. An overview of plant responses to soil waterlogging. *Plant Stress* 2(1): 20-27.

Patrick, W. H., Gambrell, R. P., and Faulkner, S. P. 1996. Redox Measurements of Soils. In: Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Patrick, W. H., Gambrell, R. P., and Faulkner, S. P. (eds.), *Methods of Soil Analysis Part 3-Chemical Methods*. Soil science Society of America, Madison, USA, pp. 1255-1273.

Pedrazzini F. R. and McKee, K. L. 1984. Effect of flooding on activities of soil dehydrogenases and alcohol dehydrogenase in rice (*Oryza Sativa* L.) roots. *Soil Sci. Plant Nutr.* 30(3): 359-366.

Phillips, I. R. and Greenway, M. 1998. Changes in water-soluble and exchangeable ions, cation exchange capacity, and $phosphorus_{max}$ in soils under alternating waterlogged and drying conditions. *Commun. Soil Sci. Plant Anal.* 29: 51-65.

Ponnamperuma, F. N. 1972. The chemistry of submerged soils. *Adv. Agron.* 2: 9-96.

Ponnamperuma, F. N. 1984. Effects of flooding on soils. In: Kozlowski, T. (ed.), *Flooding and Plant Growth.* Academic Press, New York. pp. 9-45.

Poot, A., Gillissen, F., and Koelmans, A. A. 2007. Effects of flow regime and flooding on heavy metal availability in sediment and soil of a dynamic river system. *Environ. Pollut.* 148: 779-787.

Porter, G. S., Bajita-Locke, J. B., Hue, N. V., and Strand, D. 2004. Manganese solubility and phyto-toxicity affected by soil moisture, oxygen levels, and green manure additions. *Comm. Soil Sci. Plant Anal.* 35: 99-116.

Raiesi, F. 2017. A minimum data set and soil quality index to quantify the effect of land use conversion on soil quality and degradation in native rangelands of upland arid and semiarid regions. *Ecol. Indicators* 75: 307-320.

Ramamoorthy, B. and Bajaj, J. C. 1969. Available nitrogen, phosphorus and potassium status of Indian soils. *Fertil. News* 14: 25-36.

Reddy, K., Tripathi, S., Singh, A. K., Rao, M., Subba, A., and Anand, S. 2001. Sulphate sorption-desorption characteristics in relation to properties of some acid soils. *J. Indian Soc. Soil Sci.* 49(1): 74-80.

Reeuwijk, L. P. 2002. *Procedures for Soil Analysis* (6^{th} Ed.). International Soil Reference and Information Centre-Food and Agriculture Organization, Wageningen, The Netherlands, 120p.

Rengel, Z. 2004. Aluminium cycling in the soil-plant-animal-human continuum. *Biometals* 17: 669-689.

Rinklebe, J. and Langer, U. 2006. Microbial diversity in three floodplain soils at the Elbe River (Germany). *Soil Biol. Biochem.* 38(80): 2144-2151.

Sah, R. N. and Mikkelsen, D. S. 1989. Phosphorus behavior in flooded-drained soils. i. effects on phosphorus sorption. *Soil Sci. Soc. Am. J*. 53: 1718-1722.

Saha, A. K. 2004. *Text Book of Soil Physics*. Kalyani Publishers, New Delhi, 500p.

Saha, A. K. 2008. *Methods of Physical and Chemical Analysis of Soil*. Kalyani Publishers, New Delhi, 488p.

Sahrawat, K. L. 1998. Flooding soil: a great equalizer of diversity in soil chemical fertility. *Oryza* 35: 300-305.

Sahrawat, K. L. 2004. Organic matter accumulation in submerged soil. *Adv. Agron.* 81: 169-201.

Sahrawat, K. L. 2010. Reducing iron toxicity in lowland rice with tolerant genotypes and plant nutrition. *Plant Stress* 4(2): 70-75.

Sahrawat, K. L. 2012. Soil fertility in flooded and non-flooded irrigated rice systems. *Arch. Agron. Soil Sci.* 58(4): 423-436

Sahu, R. K., Rawat, A. K., and Rao, D. L. N. 2015. Traditional rainwater management system (‘Haveli’) in Vertisols of central India improves carbon sequestration and biological soil fertility. *Agric. Ecocyst. Environ*. 200: 94-101.

Sharma, K. L., Mandal, U. K., Srinivas, K., Vittal, K. P. R., Mandal, B., Grace, J. K., and Ramesh, V. 2005. Long-term soil management effects on crop yields and soil quality in a dry land Alfisol. *Soil Tillage Res.* 83: 246-259.

Sims, J. R. and Johnson, G. V. 1991. Micronutrient soil tests. In: Mortvedt, J. J., Cox, F. R., Shuman, L. M., and Welch, R. M. (eds.), *Micronutrient in Agriculture* (2^{nd} Ed.). Soil Science Society of America, Madison, USA, pp. 427-476.

Singh, G., Sharma, M., Manan, J., and Singh, G. 2016. Assessment of soil fertility status under different cropping sequences in District Kapurthala. *J. Krishi Vigyan* 5(1): 1-9.

Smith, J. L. and Doran, J. W. 1996. Measurement and use of pH and electrical eonductivity for soil quality analysis. In: Doran, J. W. and Jones, A. J. (eds.), *Methods for Assessing Soil Quality*. Soil Science Society of America Special Publication 49, Madison, WI, pp. 169-185.

Solaiman, Z. and Hirata, H. 1995. Effects of indigenous arbuscular mycorrhizal fungi in paddy fields on rice growth and N, P, K nutrition under different water regimes. *Soil Sci. Plant Nutr*. 41(3): 505-514.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for estimation of available nitrogen in soils. *Curr. Sci*. 25: 328-330.

Sujatha, M. P., Bhindhu, P. S., Sandeep, S., Sureshkumar, P., Kavitha, C., and Remya, E. B. 2013. Soil fertility: Thrissur District. In: Rajasekharan, P., Nair, K. M., Rajasree, G., Sureshkumar, P., and Narayanankutty, M. C. (eds.), *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board, Thiruvananthapuram, pp. 419-442.

Sureshkumar, P., Bhindhu, P. S., Geetha, P., and Santosh, C. 2013. Chemistry of soils and plant nutrient dynamics. In: Rajasekharan, P., Nair, K. M., Rajasree, G., Sureshkumar, P., and Narayanankutty, M. C. (eds.), *Soil Fertility Assessment and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board, Thiruvananthapuram, pp. 93-106.

Sureshkumar, P., Geetha, P., and Bhindhu, P. S. 2018. Chemistry and fertility-management of humid tropical soils of Kerala as influenced by topography and climate. *Indian J. Fertil*. 14(3): 30-44.

Tabatabai, M. A. 1982. Sulfur. In: Page, A. L., Keeney, D. R., Baker, D. E., Miller, R. H., Ellis, R., and Rhoades, J. D. (eds.), *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* (2nd Ed.). American Society of Agronomy, Madison, USA, pp. 501-538.

Thomas, C. G. 2010. *Land Husbandary and Watershed Management*. Kalyani Publishers, New Delhi, 716p.

Tsadilas, C. D. and Kassioti, T. 2005. Influence of liming and nitrogen forms on boron uptake by tobacco (Nicotiana tabacum). *Commun. Soil. Sci. Plant Anal.* 36: 701-708.

Unger, I. M., Kennedy, A. C., and Muzika. R. 2009. Flooding effects on soil microbial communities. *Appl. Soil Ecol.* 42: 1-8.

Vanilarasu, K. and Balakrishnamurthy, G. 2014. Influences of organic manures and amendments in soil physiochemical properties and their impact on growth, yield and nutrient uptake of banana. *Bioscan* 9(2): 525-529.

Venugopal, V. K., Nair, K. M., Rajasekharan, P., and Nair, A. N. S. 2019. Soil Health Management for Sustainable Crop Production in Kerala. Department of Agriculture Development and Farmers Welfare, Govt. of Kerala, 426p.

Walker, L. R. 2012. *The biology of disturbed habitats*. Oxford University Press, New York, 318p.

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 37(1): 29-38.

Wang, F. L. and Bettany, J. R. 1993. Influence of freeze-thaw and flooding on the loss of soluble organic carbon and carbon dioxide from soil. *J. Environ. Qual.* 22: 709-714.

Watanabe, I. and Furusaka, C. 1980. Microbial ecology of flooded rice soils. *Adv. Microb. Ecol.* 4: 125-168.

Weber, J., Drozd, J., and Licznar, M. 1998. Characteristic of soil subjected to flood in July 1997 at the region of Lubsza community-situation after 5 months. *Int. Agrophysics* 12: 249-257.

Wilson, J. S., Baldwin, D. S., Rees, G. N., and Wilson, B. P. 2011. The effects of short-term inundation on carbon dynamics, microbial community structure and microbial activity in flood plain soil. *River Res. Appl*. 27: 213-225.

Witt, C., Gaunt, J. L., Galicia, C. C., Ottow, J., and Neue, H. 2000. A rapid chloroform-fumigation extraction method for measuring soil microbial biomass carbon and nitrogen in flooded rice soils. *Biol. Fertil. Soils.* 30: 510-519.

Wlodarczyk, T., Stepniewski, W., and Brzezinska, M. 2002. Dehydrogenase activity, redox potential and emission of carbon di oxide and nitrous oxide from Cambisols under flooding conmdition. *Biol. Fertil. Soils* 36: 200-206.

Wolinska, A. and Stepniewska, Z. 2012. Dehydrogenase activity in the soil environment. In: Canuto, R. A. (ed.), *Dehydrogenases.* Intech, Rijeka. Available: http://www.ebook3000.com. [28 Feb, 2020].

Yoder, R. E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of the erosion losses. *J. Am. Soc. Agron*. 28(5): 337-351.

Zhang, Y., Lin, X., and Werner, W. 2003. Effect of soil flooding on the transformation of Fe oxides and the adsorption/desorption behaviour of phosphate. *J. Plant Nutr. Soil Sci.* 166: 68-75.

ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF NORTH CENTRAL LATERITES (AEU 10) IN THRISSUR DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

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ABSTRACT OF THE THESIS

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Abstract

The Agro-ecological unit designated as North Central Laterites (AEU 10) represent midland laterite terrain. The soil is basically poor in humus, low in bases and silica, with dominance of kaolinitic clay and sesquoxides. Heavy rainfall and stagnant water create partially or completely reduced state in soil, alter biochemical activities and cause physical modifications. The deluge of August 2018 had triggered great variation in the soil environment with drastic changes in soil fertility posing threat to crop productivity. 'Soil quality' is an extensively used term to describe the functional capability of soil, which primarily depends on its dynamic properties that significantly change under environmental disturbances. The present study entitled "Assessment of soil quality in the post flood scenario of North Central Laterites (AEU 10) in Thrissur District of Kerala and mapping using GIS techniques" was undertaken to relook and evaluate the altered status of soil quality in the affected areas and to develop maps on soil characteristics and soil quality using GIS techniques.

One hundred geo-referenced surface soil samples (0-20 cm) were collected from severely affected locations comprising eleven *grama panchayats* of AEU 10 in Thrissur District. The samples were processed and characterised for physical, chemical and biological properties. Bulk density of soil ranged from 0.67 to 1.64 Mg m^{-3} and was found to be less than 1.40 Mg m^{-3} in eighty one per cent of the samples. Soil porosity was medium (30-50%) in ninety six per cent of samples and water holding capacity of soils ranged from 23.16 to 43.78%. Aggregate stability analysed in terms of mean weight diameter (MWD) ranged from 0.63 to 5.39 mm.

Ninety two per cent of samples were acidic in reaction of which forty seven per cent were extremely to strongly acidic (pH 3.5-5.5). Available nitrogen content was found to be low (<280 kg ha^{-1}) in fifty three per cent of the soils, while the concentration of available phosphorus was very high in all samples. Ninety seven per cent soils were medium to high in available potassium (>116 kg ha^{-1}) and sufficient (>300 mg kg^{-1}) with respect to available calcium. Deficiency of available magnesium (<120 mg kg^{-1}) was observed in sixty seven per cent samples, whereas all the soils were sufficient in available sulphur status. Due to leaching of boron as boric acid

under acidic soil conditions, deficiency of available boron was predominant in seventy nine per cent of the samples.

Soil organic carbon content varied from 0.40 to 3.75 per cent and the content was high (>1.50 %) in twenty nine per cent of the samples and medium (0.75-1.5%) in fifty seven per cent of the samples. Low content of microbial biomass carbon (24.99 to 1022µg g^{-1}) and dehydrogenase activity (1.02 to 532.00 µg TPF g^{-1} $24h^{-1}$) was recorded in the soils, which indicated poor survival and activity of microorganisms.

Soil organic carbon content showed strong positive correlation with porosity, water holding capacity, and aggregate stability and strong negative correlation with bulk density and particle density. Available nitrogen in soil was found to have strong positive correlation with organic carbon. Exchange acidity showed significant negative correlation with soil pH and available calcium, indicating the replacement of calcium with aluminium on soil exchange sites at lower pH

Nutrient index of the flood affected areas of AEU 10 in Thrissur District was low (<1.67) with respect to available nitrogen, and high (>2.33) with respect to available phosphorus and potassium. Soil Quality Index (SQI) was formulated from the weighted scores of key indicators, selected through principal component analysis. Available calcium, soil pH, bulk density, available phosphorus, copper, boron, nitrogen and microbial biomass carbon were found to be the key indicators. A strong positive correlation (0.79^{**}) was observed between the non-linear and linear scoring methods employed to compute the Soil Quality Index. The mean value of SQI ranged from 0.50 to 0.70 and from 0.71 to 0.87 as per non-linear and linear scoring methods respectively. Soil pH and bulk density were found to have the highest contribution to SQI whereas, the lowest contribution was by available boron, followed by microbial biomass carbon and available nitrogen.

The study also showed that the relative soil quality index (RSQI) was medium in more than 80 per cent of the sampling locations and poor in 13 locations. The mean relative soil quality index (RSQI) of all *panchayats* ranged from 50-70 % and was rated as medium. Shifting of key indicators from the optimal range contributed to decline in SQI. Consequently, site specific soil management practices to optimize quality indicators can improve soil fertility and enhance productivity.