ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF AEU 5 AND AEU 9 OF ERNAKULAM DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

by

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(2018-11-048)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

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THESIS

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2020

DECLARATION

I hereby declare that, this thesis entitled **'Assessment of soil quality in the post flood scenario of AEU 5 and AEU 9 of Ernakulam district of Kerala and mapping using GIS techniques'** is a bonafide record of research work done by me during the course of research and that, the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or society.

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Date : 20-11-2020

CERTIFICATE

Certified that, this thesis entitled **'Assessment of soil quality in the post flood scenario of AEU 5 and AEU 9 of Ernakulam district of Kerala and mapping using GIS techniques'** is a record of research work done independently by **Ms. Neha Unni** under my guidance and supervision and that, it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

20.11.2020

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Date : 20-11-2020

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Assistant Professor & Head

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We, the undersigned members of the Advisory Committee of **Ms. Neha Unni,** a candidate for the award of degree of Master of Science in Agriculture with major in Soil Science and Agricultural Chemistry, agree that, the thesis entitled **'Assessment of soil quality in the post flood scenario of AEU 5 and AEU 9 of Ernakulam district of Kerala and mapping using GIS techniques'** may be submitted by Ms. Neha Unni in partial fulfilment of the requirements for the degree.

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Dedicated to my beloved parents and my God who made everything possible

ABBREVATIONS

Sl. No	Symbols	Explanation
1	N	Nitrogen
2	P	Phosphorus
3	K	Potassium
4	Ca	Calcium
5	Mg	Magnesium
6	S	Sulphur
7	Fe	Iron
8	Mn	Manganese
9	Zn	Zinc
10	Cu	Copper
11	B	Boron
12	MWHC	Maximum water holding capacity
13	PCA	Principal component analysis
14	PCs	Principal components
15	MDS	Minimum data set
16	SQI	Soil quality index
17	RSQI	Relative soil quality index
18	NI	Nutrient index

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Introduction

INTRODUCTION

In August 2018, Kerala witnessed large scale flooding due to excess rainfall. As per Indian Meteorological Department (IMD) data, Kerala received 2346.6 mm of rainfall from 1st June 2018 to 29th August 2018 which is 36 per cent excess from normal rainfall. The flood has resulted in landslides, water stagnation and deposition of sand/silt /clay in these areas. Flood water eroded the surface soils, leaving deep gullies and also deposited all types of debris in fields. Enormous changes took place in soil properties and soil quality as a result of flood. Assessment of soil quality after flood is very important to formulate crop management plans to restore productivity. AEU 5 and 9 were the most affected areas in Ernakulam district.

Pokkali lands (AEU 5), represent the lowlands, often below sea level, in coastal areas of Ernakulam district and extending to parts of Thrissur and Alappuzha districts. The soils are hydromorphic, often underlain by potential acid-sulphate sediments with unique hydrological conditions. Seawater inundation is not controlled and hence soils are acid-saline. The region extends from 9° 00’ to 10° 40’ N latitude and 76° 00’ to 77° 30’ E longitude. This unit covers 39,765ha of the State. The *Pokkali* region lies north of the Thannermukkam bund in Ernakulam district and south of Enamakkal regulator in Thrissur district. Traditional *Pokkali* rice cultivation and shrimp farming is practiced in the wetlands, saline tolerant traditional rice variety ‘*Pokkali’* is used in these areas. A single crop of rice is taken in one season followed by prawn farming. Rice is cultivated in low saline phase during June to mid-October and prawn farming is done during high saline phase i.e., November to April.

The south central laterites (AEU 9) are delineated to represent midland laterite terrain with typical laterite soils. The unit covers 161 panchayats of midland extends from Thrivananthapuram to Ernakulam district. Unlike the southern counterpart, the strongly acidic, lateritic clay soils here in are gravelly and often underlain by plinthite. Rubber, coconut and a variety of annuals and perennials are the land use in uplands and rice, tapioca, banana and vegetables on lowlands. The unit covers around 3,65,932 ha in the State.

Soil quality has been defined as “the capacity of soil to function with its surroundings, sustain plant and animal productivity, maintain soil, water and air quality” (Karlen *et al.*, 1997). The basic concept of soil quality has been developed to quantify the important factors that affect the ability of soil to function effectively. The importance of soil quality lies in achieving sustainable land use and management system, to balance productivity and environmental protection (De la Rosa and Sobral, 2008).

The objectives of the study are:

- Assessment of the soil quality of post flood soils of AEU 5 and AEU 9 of Ernakulam district
- To develop maps on soil characters and quality using GIS techniques
- To workout soil quality index (SQI).

Review of literature

REVIEW OF LITERATURE

Kerala being an agrarian economy, its economic growth has always been under the caprices of the weather. The extreme and persistent rainfall occurrence affected all aspects of human lives including socio-economic conditions, transportation, infrastructure, agriculture and livelihood. Kerala floods in 2018 caused major damages to land, soil and agriculture. Significant changes in the soil properties occurred after the flood due to soil erosion and soil deposition. In this context, assessment of soil quality becomes a need of the hour which should be carried out for restoring soil productivity in the flood affected areas.

2.1. KERALA FLOOD 2018

The state of Kerala experiences two monsoon seasons, that is southwest (June to September) and northeast (October to December) monsoons. The physiography of the State influences the spatio-temporal distribution of rainfall (Simon and Mohankumar 2004). The Western Ghats of Kerala experiences heavy rainfall (around 3000mm annually), of which, majority occur during the south-west monsoon (Thomas and Prasannakumar 2016). During the year 2018, State experienced higher rainfall than normal through the south-west monsoon which was an excess of 36 per cent till 29 August 2018 (IMD 2018) causing this deluge.

All districts in Kerala except Kasargode was severely affected by flood. However, unscientific methods of land utilization, unbridled mining of river channel sand and brick clay, conversion of wetland to dry land and construction of buildings in the river floodplains led to intensity of losses caused by the south-west rainfall events. This also caused a slowdown and hindered the free flow of flood waters through the natural drainage system (Vishnu *et al.*, 2019). Kerala has many large, medium and small size reservoirs that exceeded the storage limit before flooding. The combination of heavy rain fall and reservoir release worsened the flood condition (Mishra *et al.,* 2018). Moreover, water from the nearby rivers, lakes started filling up the low lying paddy fields and residential areas.

2.2. *POKKALI* LANDS

The origin, genesis and development of *Pokkali* soils are under peculiar climatic and environmental conditions. These soils comprise low lying marshes and swamps situated near streams and rivers and are not far from the sea. They are water logged and ill drained and are subjected to tidal action throughout the year, *Pokkali* field is prevalent in the coastal saline tracts of Kerala. They are able to produce paddy and shrimp rotationally in an organic way. An integrated system of rice and fish production during *Kharif* followed by prawn culture in summer is prevalent in the coastal belt of central Kerala. *Pokkali* lands are known after the renowned '*Pokkali'* rice cultivar which is internationally accepted as gene donor for salt tolerance in rice (Sasidharan, 2004). The tall rice varieties are grown without chemical fertilizers and pesticide additions (Thampy, 2002). *'Pokkali'* rice is cultivated in the *Pokkali* field during May/June to October and the remaining period November to April is utilized for prawn culture (Deepa, 2014).

2.2.1. Characteristics of *Pokkali* soils

As per Soil Taxonomy *Pokkali* soils belong to the order Inceptisols, suborder Aquepts, great group Sulfaquepts. The soil is classified as coarse loamy over sandy, mixed, active, isothermic, Typic Sulfaquepts (Nidheesh, 2019). *Pokkali* soils are acidic and low pH values are typical of these acid saline soils. *Pokkali* soils are acid saline in nature with pH ranging from 3.0 to 6.8 (Nair and Money, 1968). Electrical conductivity of soils during high saline phase i.e., November to May ranges from 12 to 24 dS m^{-1} (Sreelatha and Shlyaraj, 2017). The soil consists of soluble salts mainly of chlorides and sulphates of Na, Mg and Ca. During low saline phase i.e., June to October it varies from 0.01 to 7.8 dS m^{-1} (Sreelatha and Shylaraj, 2017), the water becomes almost fresh and salt content decreases. The soil salinity varies from 0 to 31 ppt or more. The salinity of *Pokkali* fields decrease rapidly up to the month of August and maintained till the end of December to January (Vanaja, 2013). Due to the presence of soluble salts of sodium, soils have high exchangeable sodium percentage and sodium absorption ratio (Joseph, 2014). Although the integration of rice and prawn did not alter the soil physico-chemical parameters, rotational prawn culture during summer causes positive changes in soil pH. Adverse changes like increase in electrical conductivity and Na^+ levels are mostly reversible and may not affect the sustainability of the system.

The soil is stiff impervious clay but rich in organic matter. Soil is bluish black in colour and is hard and creates deep fissures when dry and sticky when wet (Varghese *et al.*, 1970). These fields are naturally connected to the Arabian Sea through backwaters and canals (Jayan and Sathyanathan, 2010). During high saline phase i.e., November – May sea water inundation by saline water makes soils saline. *Pokkali* fields are low lying and this causes inundation of sea water. The salt content in soils is high during this phase. Prawn cultivation is practised during high saline phase. During monsoon the salts are washed off by rainfall and this is the low saline phase (June – October). During low saline phase, inherent acidity dominates (Sreelatha and Shylaraj, 2017). Specific, non-pathogenic, pigmented bacterial species of *Bacillus* isolated from sediments of *Pokkali* and perennial ponds of Njarakkal are found to inhibit growth of pathogenic bacteria by producing antagonistic antibiotics (Chandrika, 1999).

Diya and Sreelatha (2018) observed that, *Pokkali* soils are deficient in available N, P, Ca, Mg and Cu and all other nutrients were in sufficiency level. Sasidharan (2004) reported that, the increased available potassium content in the soil is due to the tidal action. Tacon (1987) reported that the amount of available calcium almost gets doubled after the harvest of prawn and this can be due to deposition of calcium rich exuvia of prawns. Calcium in the *Pokkali* lands is found in water soluble form and in complexed organic form so that available calcium content is directly influenced by tidal action and organic matter content (Bhindu, 2017). Due to the acid sulphate nature of *Pokkali* lands, high content of sulphur was reported by Santhosh (2013).

Santhosh (2013) found that, the high content of available boron in organically complexed form in lowlands of *Pokkali* tracts is mainly due to the direct marine influences along with high organic matter. Sasidharan (2004) found that, removal of Al toxicity is very difficult in *Pokkali* soil because of tidal action. The high tide and low tide occurring twice a day maintains the fertility and productivity of *Pokkali* soils (Sreelatha and Shylaraj, 2017). This tidal action is helpful for the growth of beneficial microorganisms (Ranga, 2006). Tide brings nutrients to *Pokkali* soils and removes toxic concentrations during low tide (Sreelatha and Shylaraj, 2017). The occurrence of large numbers of *Pseudomonas sp.* in *Pokkali* fields during monsoon months was reported by Pramila and Chandrika, (2001). *Pokkali* fields are the tidal wetlands and are characterised by the soluble salts accumulation of sodium over and underlying acidic soil with toxic levels of iron and manganese (Padmaja *et al.,* 1994).

2.2.2. Paddy-shrimp farming system

Pokkali farming is a typical farming system in which paddy and shrimp cultures are done alternatively in the same field (Pillai, 1999). Cultivation process of *Pokkali* rice starts in the month of April with strengthening of outer bunds and setting up of sluices to control the level of water. The fields are then drained during low tide and the sluices are closed at high tide. When the soil becomes dry, it is heaped up to form mounds of about one meter base and a half meter height. This operation is done in the month of April and the mounds are then allowed to dry in weather. With the onset of monsoon during May- June, the salt is washed off from the soil and the water with dissolved salt is drained off from the field. Tops of mounds become free from salt very soon (Tomy *et al*., 1984). When the soil and weather conditions become favourable for sowing, the baskets containing seeds are soaked in water for 3-6 hours before sowing. Then the mounds in the field are then raked and the top levelled.

The sprouted seeds are sown on the top of the mounds which act as nursery 'insitu". When the seedlings were 25 days old, the mounds were cut into pieces and seedlings with clods are uniformly spread in the entire area of the field maintaining a spacing of 20×15 cm with 2-3 seedlings per hill. By that time the seedlings will become tall enough to survive in the flooded field condition (Tomy *et al*., 1984). In order to survive in the waterlogged field, the rice plants grow up to two metres. During the harvest of the *Pokkali* crop, only the rice ear heads are removed and the rest of the stalks are left to decay in the water,. The decaying paddy stubbles provide a niche for forage organisms such as zooplanktons and phytoplanktons (Purushan, 2002).

Pokkali fields are exclusively used for fish/prawn farming after the harvest of rice. Prawn filtration is a traditional technique of prawn culture developed by innovative farmers of the *Pokkali* region (Deepa, 2014). The bunds are strengthened and the sluice gates are fixed in places where there is medium flow of water from the canal or backwater to the fields. Bund top width is 1.0 m and height is maintained at the level of 1.5 m. The length of sluice is about 3.5 m, width is 1.25 m and height is 2.25 m. Shutter planks are used to regulate the water flow into the field and planks are made up of the wood (Sudhan *et al.*, 2016). Nylon net sluice screen that guards the escape of shrimps or fishes from the field during discharge of water. After these preliminary preparations water is let into the fields during high tide at night, through the sluice. Organic wastes after harvest of paddy cultivation is allowed as the natural feed material for shrimp/fish culture (Sudhan *et al.*, 2016). No supplementary stockings or supplementary feedings are used in this system (Shylaraj *et al*., 2013). Fish and shrimps that are trapped in the field are harvested when they reach a marketable size.

2.3. SOUTH CENTRAL LATERITES

The south central laterite soils are the most extensive in the state and the unit covers about 3,65,932 ha i.e., 9.42% of the total area of Kerala. Laterite soils cover almost entire midlands, part of coastal lands and Wayanad plateau and occupy the major portion of the agro ecological unit. The soils are often deep to very deep, gravelly, sandy clay loam to gravelly clay surface texture, well drained, acid clay with plinthite occurring at various depths. The soils are extremely gravelly in the surface and shows wide variation within the profile. Mostly kaolinite type clay is predominant with very low cation exchange capacity. They are strongly acid soils with low reserves of bases and deficient in plant nutrients. They are well drained soil and have moderate permeability with fairly good air water relationships and have good structural characteristics due to the presence of oxides of iron and aluminium.

Laterite soils have serious constraints to crop production viz., gravelliness, low water retention, strong soil acidity, low organic matter content, low base saturation, aluminium toxicity, low plant nutrient retention, multi-nutrient deficiency, and high phosphorus fixing capacity. However, with protection from erosion and with application of adequate external inputs such as lime, organic matter, macro, secondary and micronutrients, the laterite soils can be enabled support very high biomass production with plantation and annual crop production systems. They are distributed on steep sloping lands and are prone to erosion. Rubber, coconut intercropped with a variety of annuals and other perennial crops is the major land use on uplands and rice, cassava, banana and vegetables on lowlands (GoK, 2013).

2.4. EFFECT OF FLOOD ON SOIL QUALITY

Flooding can significantly alter the level of plant available nutrients in the soil. Soil lost due to erosion leads to loss of valuable plant available nutrients and organic matter. Deposition of sediments from floods may increase the level of nutrients in the soil. Nelson and Terry (1996) observed that, bulk density has a greater influence on denitrification activities of flooded soils. Under flooded soil conditions, losses of soil available nitrogen can be considerable, there is a chance for leaching down of nitrate nitrogen from root zone. The soil moisture content increased to higher extent and soil physical properties such as porosity are poor during flooding. Availability of phosphorus generally increases during flooding in crops especially under rice (Ubouh *et al.,* 2016).

The physical attributes such as bulk density, water holding capacity, porosity and particle density were found to be almost same even after flooding. During flooding availability of manganese might increase. The pH value of the soil from flooded field was found to be less when compared to the normal soil condition, this could be due to the normal washing of soil by flooded water (Kalshetty *et al.*, 2012). Due to the effect of flooding, increased organic carbon content was recorded in flood affected cultivated areas in Bagalkot (Kalshetty *et al.,* 2012). The electrical conductivity may increase from prescribed limit, this may be due to the deposition of dissolved salts. The available potassium and phosphorus content was found to be increased after flooding. The deposition of silt or alluvium might be the reason for the increased potassium content in the soil. The available magnesium and exchangeable acidity also reduced after flooding (Ubouh *et al.,* 2016).

2.5. CONCEPT OF SOIL QUALITY

Soil quality has been defined as ‘the capacity of soil to function with its surroundings, sustain plant and animal productivity, maintain soil, water and air quality’ (Karlen *et al.,* 1997). Soil quality appears to be an ideal indicator of sustainable land management (Herrick, 2000). Soil has two types of soil quality viz; inherent and dynamic soil quality. Inherent soil quality is a soil’s natural ability to function and dynamic soil quality is changes in soil according to the soil management. Management choices affect the amount of soil organic matter, soil structure, and water holding capacity (De la Rosa and Sobral, 2008).

Several studies has shown that, organic farming leads to higher soil quality with higher microbiological activity than conventional farming, due to versatile crop rotations, reduced application of synthetic nutrients and the absence of pesticides in crop production (Hansen *et al.,* 2001). It is well known that, soil organic matter is one of the best indicators responsible for maintaining better soil health, soil quality and crop production (Chandel *et al.,* 2018).

Doran and Zeiss (2000) stated that, the term soil quality is associated with a soil's fitness for use. Warkentin and Fletcher (1977) developed soil quality by integrating the relationship of soil quality with the land function. Environmental quality greatly depends on soil quality factors and soil quality.

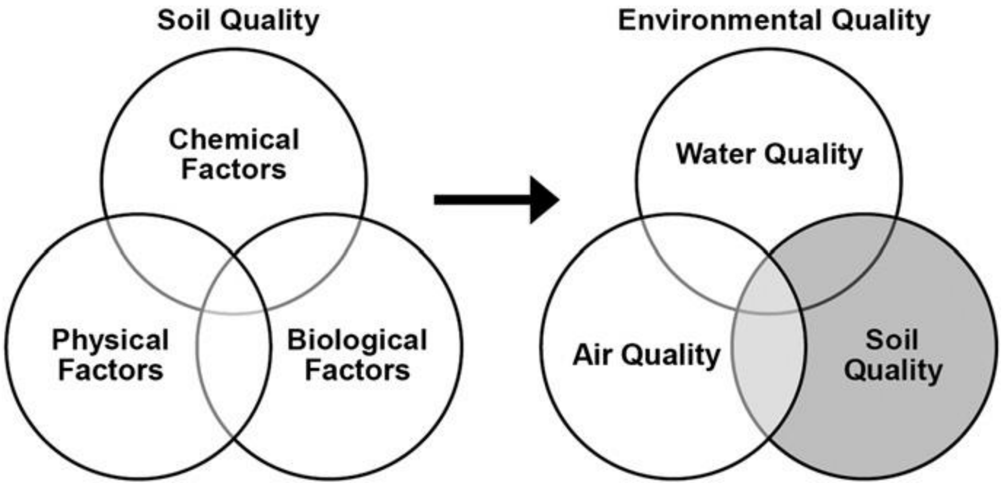

Fig 1. Relationship between soil quality and environmental quality (Bone *et al.*, 2010)

The concept of soil quality was evolved in the 1990's in response to increased global emphasis on sustainable land use and with a comprehensive focus accentuating, sustainable soil management for better soil erosion control. The importance of soil quality lies in achieving sustainable land use and management system, to balance productivity and environmental protection (De la Rosa and Sobral, 2008). The basic concept of soil quality has been developed to quantify the important factors that affect the ability of a soil to function effectively. It provides early warning signs of adverse trends in the soil to the farmers (Bindraban *et al.,* 2000). Obade and Lal (2016) elucidates the interconnection between on farm soil quality contradictory to crop yields by impartially amalgamating soil attributes from different management scenarios and soil layers. To evaluate the degradation status and changing trends due to adoption of various soil management practices, soil quality assessment is necessary (Lal, 1995).

The concept of soil quality advanced when the Natural Resources Conservation Service (NRCS) Soil Quality Institute was constituted and the USDA-Soil Conservation Service was reoriented. Most important factors associated with the soil quality concept are (1) soils have both inherent and dynamic properties and processes (2) soil quality assessment must reflect biological, chemical, and physical properties, processes and their interactions (Karlen *et al.,* 2003).

The important factors that effects soil quality are tillage, crop rotation, type of manure applied, climate and soil type (Imaz *et al.,* 2010). The data on soil physical, chemical and biological properties are essential to assess soil quality. Different chemical, physical, and biological properties of a soil interact in complex ways that determine its potential fitness or capacity to produce healthy and nutritious crops. (Parr *et al.,* 1992). Sharma and Mandal (2009) listed water logging, salinity, alkalinity and formation of acid sulphate soil as the predominant reasons of land degradation and poor soil quality. Soil management practices greatly influences soil quality which should be widely studied from plot to national scales and worldwide (Qi *et al.,* 2009).

The soil quality of wetlands is seriously influenced by many environmental processes such as sediment deposition, delta accretion, freshwater–saltwater interaction and material-energy exchanges (Bai *et al.,* 2012).

2.5.1. Soil functions

Soil can have multiple functions. Sojka and Upchurch (1999) described that, how soil performs several functions simultaneously and there is considerable overlap in the functions of soil. Major functions of soil are: 1) maintains biological activity and productivity, 2) serves as a medium for plant (food/fibre) growth, supports plant productivity/yield, 3) supports human/animal health 4) acts as a biodiversity and gene pool, 5) partitions and regulates water/solute flow through the environment, 6) serves as an environmental buffer or filter, 7) maintains environmental quality, 8) cycles nutrients, water, energy and other elements through the biosphere, 9) supports socio-economic structure, cultural and aesthetic values and a platform for human activities and landscape and 10) an archive of heritage (EC, 2006; Loveland and Thompson, 2002; Karlen *et al.,* 1997; Sombroek and Sims, 1995). Daily (2000) defined the soil functions as, that generally fit in with the definition of ecosystem services, the benefits that human beings gain from natural ecosystems.

2.6. SOIL QUALITY ASSESSMENT

Soil quality assessment is one of the ways to develop strategies to improve the sustainability of land and productivity of the crop. It is a promising tool for monitoring and analysing the effects of different soil types on crop performances, both biological and economic yields (Suryanto *et al.,* 2017). The soil quality assessment is based on a combination of soil environmental quality, soil sustainability and soil productivity (Liu *et al.,* 2016). Major challenge in soil quality assessment was that, there were no established standards and soils vary widely (Stocking, 2003). Difference in management practices on the same soil type is an important point to be considered for soil quality assessment (Norfleet *et al.,* 2003).

The soil quality concept includes two areas of emphasis viz; education and assessment both based on principles of soil science. Soil quality assessment and education are pre-determined to provide a better understanding of soil resources such as truly living bodies with biological, chemical and physical properties and processes performing essential ecosystem services (Bone *et al.,* 2010).

There are different soil quality assessment models based on different methods and data, but none of these models can fully meet all purposes. The selection of suitable soil classification model has become an important aspect in soil quality assessment (Liu, *et al.,* 2016). Soil quality assessment is generally based on an aggregation of soil environmental quality, soil productivity and soil sustainability. Many researchers are concerned with the assessment of soil heavy metal contamination or soil fertility, it is rare that research combines these two approaches to assess soil quality. This is possible because there is a complex nonlinear relationship between soil heavy metal content and soil fertility and because traditional methods could not perform well in addressing with the complex nonlinearity (Taylor *et al.,* 2010; Teng *et al.,* 2014).

De la Rosa and Sobral (2008) found that, the need to assess soil quality has become the most important target for the modern soil science, because of growing interest of public in sustainability and desire to determine the effects of land and management practices on soil resources.

Carter *et al*. (1997) suggested a framework for evaluating soil quality that includes describing each soil function on which quality is to be used, selecting soil characteristics of properties that influence the capacity of the soil to provide each function, choosing indicators of characteristics that can be measured and using methods that provide accurate measurement of those indicators.

2.6.1. Methods of soil quality assessment

There are different methods for soil quality assessment which includes soil quality index (SQI) methods, soil quality cards and test kits, fuzzy association rules and soil quality models (Ditzler and Tugel 2002; Andrews *et al*., 2002; Doran and Parkin 1994; Xue *et al.*, 2010; Larson and Pierce 1994).

The soil quality cards and test kits are used for on-farm tests. The SQI was calculated using an indexing technique, it has three main steps 1) selection of quality indicators, 2) scoring of selected indicators and 3) calculation of soil quality index (Andrews *et al.*, 2002). Fuzzy association rules (FARs) can be powerful in assessing regional soil quality. However, little importance has been reported in evaluating land resources (Xue *et al.*, 2010). Modelling is the fundamental component for the assessment of dynamic and inherent soil quality. The models provide a tool for predicting the changes in outcome caused by the soil parameters (De la Rosa and Sobral, 2008).

2.6.2. Soil quality indicators

The soil quality evaluation from plot to regional scale, is based on the use of selected physical, biological and chemical indicators, sensitive to soil disturbance, land-use changes or any input into the soil system (Brejda *et al.*, 2000).The predominant soil quality indicators at micro and macro farm scale are grouped into three sections such as physical indicators, chemical indicators and biological indicators (Singer and Ewing, 2000).

Burger and Kelting (1999) proposed that, good indicators should have the following characters:1) possess an available baseline to compare the change, 2) sensitive and timely measure of a soil's ability to function, 3) be applicable over large areas but specific enough to be sensitive, 4) capable of providing a continuous assessment, 5) inexpensive, easy to use, collect, and calculate, 6) discriminate between natural changes and those induced by management, 7) highly correlated to long-term response and 8) responsive to corrective measures.

Soil quality can be assessed by integrating physical, chemical, and biological attributes that give priority to the management induced changes in soil condition by land use changes (Doran and Parkin 1994; Karlen and Stott 1994; Raiesi 2017). The three main categories of indicators are:

i) Physical indicators: Commonly used physical indicators for soil quality assessment are bulk density, porosity of the soil, texture of the soil, water holding capacity, soil moisture content, compaction, aggregate stability and infiltration (Xue *et al.,* 2010). Wander and Bollero (1999) accentuated that among the physical indicators, bulk density and mean weight diameter of aggregates are the good indicators of soil quality because they are environmentally relevant and sensitive to management. Physical indicators provides information about aeration, hydration status, water holding capacity, root zone water and also gives information on nutrient availability and plant growth. Boehm and Anderson (1997) illustrated that aggregate size and stability can denote the changes in soil quality as a result of soil management.

ii) Chemical indicators: Chemical indicators include pH, electrical conductivity, salinity, organic carbon content in the soil, cation exchange capacity, exchangeable acidity, available nutrients to the soil and concentration of potential toxic elements. The chemical indicators are the most important attributes which determine the soil quality (Nortcliff, 2002). The soil chemical indicators have a well-established procedure available for interpreting results.

iii) Biological indicators: Biological indicators may be very dynamic and very sensitive to changes to soil conditions. Attributes that are measured include enzyme activity of the soil, microbial biomass carbon, respiration rate which indirectly evaluate the microbial activity and populations of macro, meso and microorganisms (Joseph, 2014). Lima *et al.* (2013) found that biological indicators are the most sensitive in illustrating differences in soil quality under rice production systems. Cropping system and management practices have significant effects on all soil properties, the soil attributes that are most sensitive to these managements are most desirable soil quality indicators. In the case of biological indicators, the interpretation and measurements in relation to crop yield or environmental effects is in its infancy, and there is not yet any agreed scientific basis on which to make such determinations (Wolfe, 2006). Several studies have underscored that, soil quality assessment still focused on soil physical and chemical indicators, but rarely described by biological indicators (Bastida *et al.*, 2008).

2.6.3. Concept of minimum data set

Several soil quality indicators collectively form a comprehensive measurement known as minimum data set (Makalew, 2011). Minimum data set (MDS) can be used to determine the performance of the critical soil functions associated with each management goal (Sharma and Mandal, 2009). The identification of minimum data set indicators that integrate both qualitative and quantitative information as a major challenge in developing SQI (Guo *et al.*, 2017). The selection of the MDS can be done using different methods such as principal component analysis, linear and multiple regression analysis, discriminant analysis and scoring functions. The most widely used method to identify the MDS is principal component analysis because it can reduce redundant information in the original data set (Yao *et al.*, 2013). Once the minimum data set is fixed and the soil indicators are identified, the analysis of the values of the proposed soil quality indicators needs to be distinct.

2.6.4. Soil quality index

Soil quality assessment can be made by analysing the soil properties, establishing minimum data set (MDS) and calculate the soil quality index (SQI) (Liu, *et al.*, 2017). Due to simplicity and quantitative flexibility, the soil quality index method is most commonly used (Rahmanipour *et al.*, 2014). There are three main steps involved in the soil quality index method which includes (i) selection of a minimum data set (MDS) of indicators which includes the most significant variables that best represent the soil functions (ii) development of the MDS indicators and scores are given to each indicators (iii) integration of the indicator scores and calculation of index of soil quality.

1) Indicator selection

Principal component analysis (PCA) was employed as a data reduction tool to select the most appropriate indicators for a minimum data set (MDS). Principal component analysis with simple or multiple correlation analysis is an appropriate method for selecting indicators (Zuber *et al.*, 2017). Firstly, only the calculated principal components (PCs) with the eigen values being greater than or equal to 1, and those that explained at least 10 % of the data variation, were considered as members of MDS. Secondly, for these primarily selected members, only the indicators with absolute factor loading values being greater than or equal to 0.6 were considered for the MDS. If a certain soil indicator had high loading (>0.6) concurrently in two PCs, it would be categorized into a group in which other soil indicators were less correlated with it. Furthermore, these selected indicators of MDS were weighted based on the norm value (Yemefack *et al.*, 2006), and indicators with the absolute values after weighting within 10 per cent of the highest indicator's absolute value were selected for the MDS (Andrews *et al.*, 2002).

2) Indicator scoring

To avoid the effects due to dimension and magnitude of different indicator units, the selected MDS indicators were transformed into unit less scores ranging from 0 to 1 based on their contribution to soil functions (Andrews *et al.*, 2002). The non-linear scoring methods are the most commonly used methods (Bastida *et al.*, 2006). For non-linear scoring, the following sigmoidal function is used

$$S_{NL} = a/1+(X/X_m)^b$$

where S_{NL} is the non-linear score of the soil indicator, a is the maximum score reached by the function which is equal to 1, X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation and is set as −2.5 for a '*more is better*' curve and 2.5 for a '*less is better*' curve (Bastida *et al.*, 2006; Raiesi, 2017).

3) Calculation of SQI

Soil quality index (SQI) was calculated using the method described by Doran and Parkin (1994):

Soil quality index = $\sum_{i=1}^{n} Wi \times Si$

where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA. The method to obtain the weight value of selected PCs having eigen value >1 is given as:

Weighing factor = % variance / cumulative %

Here the assumption is that, higher index scores meant better soil quality or greater performance of soil function. For better understanding and relative comparison of the long term performance of the conjunctive nutrient use treatments, the SQI values were reduced to a scale of 0–1 by dividing all the SQI values with the highest SQI value.

Govaerts *et al.* (2006) and many other researchers (Jha and Mohapatra, 2012; Lyu and Chen, 2016; Sharma *et al.,* 2016;Yu *et al*., 2018,) followed the same procedure of soil quality index, where key indicators are screened through principal component analysis (PCA), normalised and then integrated into weighted additive SQI.

Development of soil quality index for the site can be used as a decision making tool for policy formulation for land restoration and reclamation of ravinous wasteland of the semi-arid region of India (Jha and Mohapatra, 2012). Joseph (2014) reported that, the highest soil quality index was observed in paddy- shrimp land use system and least in shrimp alone land use system in *Pokkali* lands. A sturdy SQI should be sensitive to changes in soil functions, sensitive to soil management and easily measurable (Armenise *et al.,* 2013).

2.6.5. Types of soil quality indices

Different types of soil quality indices were developed to assess soil quality. Soil quality index was developed for different land uses (Marzaioli *et al.*, 2010), for land use change (Li *et al.*, 2013), for different climatic condition (Sanchez-Navarro *et al.*, 2015) and for different regions of the world (Nortcliff, 2002). There is no universal method to assess soil quality under different environmental conditions.

Therefore many conceptual frameworks and models have been proposed to evaluate soil quality (Sione *et al.*, 2017). For soil quality assessment of tropical semi evergreen forest and shifting cultivation, weighted soil quality index (SQI_w) was proved to be most sensitive to assess the impact of these two land uses. Both the depth of the soil and the land use depends on the quality of the studied soil (Mishra *et al.*, 2017). SQI was an effective tool to assess the influences of different land uses on soil quality and soil quality assessment can be done in areas similar to alpine grassland using SQI (Yu *et al.*, 2018).

Materials and methods

MATERIALS AND METHODS

The study was undertaken to understand the changes in the soil quality after the 2018 floods in AEU 5 (*Pokkali* soils) and AEU 9 (South Central Laterites) of Ernakulam district, and to develop soil quality maps using GIS techniques. Geo-referenced soil samples were collected from different locations in AEU 5 and AEU 9. The study was conducted at the College of Horticulture, Vellanikkara during 2018-2020. The methodology followed are listed below.

3.1 DETAILS OF THE LOCATION

A survey was conducted to identify the flood affected areas of AEU 5 and AEU 9 of Ernakulam district. Representative geo-referenced soil samples from selected locations of AEU 5 and 9 containing 5 soil samples from each location were collected to form one composite sample. A total of 100 geo-referenced soil samples were collected and characterized for physical, chemical and biological properties.

The *Pokkali* lands, comes under AEU 5, lowlands which is often below sea level, in the coastal areas of Ernakulam district and extending to parts of Thrissur and Alappuzha districts. The region is situated between latitude of 9° 00’ to 10° 40’ N and a longitude of 76° 00’ to 77°30’ E. The unit covers about 34 panchayats with an area of 39,765 ha in the State. The hydrology and soils are similar to those in Kuttanad, however sea water inundation is not controlled and hence soils are acid-saline.

The south central laterites, coming under AEU 9, represent the midland laterite terrain with typical laterite soils. The unit covers 161 panchayats of midlands extending from Thiruvananthapuram to Ernakulam district, with an area of 3,65,932 ha in the State.

3.2 COLLECTION OF SAMPLES

A total of 100 composite soil samples were collected from Ernakulam district. From AEU 5, 36 surface soil samples were collected during June 2019 and remaining 64 from laterite soils (AEU (9) of Ernakulam district during July to August 2019. From each sampling site, soil samples were collected to a depth of 0-15 cm using core sampler. Composite samples were collected by taking 5 core samples randomly from one meter distance in a sampling site, mixed and quartered to 500 to 1000g soil. The collected samples were immediately sealed in plastic covers and labelled. Geographical co-ordinates of sampling sites were recorded using GPS.

3.3 LAND USE

A special kind of rice cultivation, locally known as *Pokkali* cultivation is practiced in AEU 5. The different land uses in *Pokkali* are paddy alone, paddy – shrimp or fish alone systems. In AEU 9 of Ernakulam, main crops seen are nutmeg, banana, coconut and vegetables.

Table 1: Details of sites- AEU 5

Sample No.	Name of the panchayats	N latitude	E longitude
1	Kadamakkudy	10°3’2.7638”	76°19’7.9062”
2	Kadamakkudy	10°3’57.4222”	76°15’45.3093”
3	Varapuzha	10°4’42.5753”	76°15’53.9866”
4	Varapuzha	10°3’46.1736”	76°16’42.8746”
5	Varapuzha	10°3’46.1738”	76°16’42.8748”
6	Kottuvally	10°7’6.564”	76°14’53.502”
7	Kottuvally	10°6’49.4020”	76°14’27.9596”
8	Kottuvally	10°6’49.40208”	76°14’27.95964”
9	Chittatukkara	10°8’43.8133”	76°12’6.9770”
10	Ezhikkara	10°6’44.3345”	76°13’38.2023”
11	Ezhikkara	10°6’20.8792”	76°13’51.4772”
12	Ezhikkara	10°6’19.1584”	76°14’21.1981”

13	Kadamakkudy	10°3’16.9053”	76°15’11.4899”
14	Mulavukad	9°59’23.1064”	76°14’59.8401”
15	Elamkunnapuzha	10°10’25.6152”	76°10’37.7726”
16	Njarakkal	10°2’8.8055”	76°13’51.2588”
17	Njarakkal	10°2’41.9037”	76°13’38.3454”
18	Nayarambalam	10°3’43.0916”	76°13’20.0828”
19	Edavanakkad	10°4’49.6313”	76°12’58.1568”
20	Edavanakkad	10°4’47.8470”	76°12’55.6177”
21	Edavanakkad	10°6’27.9919”	76°11’49.5179”
22	Edavanakkad	10°6’51.0251”	76°11’47.5888”
23	Kuzhuppilly	10°6’50.4957”	76°11’54.6666”
24	Kuzhuppilly	10°6’50.0360”	76°11’12.2179”
25	Pallippuram	10°8’5.1257”	76°12’7.4692”
26	Puthenvelikkara	10°9’53.8923”	76°14’32.901”
27	Puthenvelikkara	10°9’49.635”	76°14’48.9242”
28	Chendamangalam	10°10’13.3441”	76°14’1.9767”
29	Chendamangalam	10°10’26.5180”	76°14’6.62352”
30	Chendamangalam	10°10’11.7236”	76°13’59.2971”
31	Chendamangalam	10°10’32.4130”	76°14’18.6723”
32	Vadakekkara	10°10’18.3385”	76°12’43.1247”
33	Vadakekkara	10°10’37.6849”	76°15’20.5336”
34	Vadakekkara	10°10’25.8884”	76°12’42.4911”
35	Vadakekkara	10°10’25.9704”	76°12’44.2909”
36	Vadakekkara	10°9’45.4978”	76°12’42.8817”

Table 2: Details of sites - AEU 9

Sample No.	Name of the panchayats	N latitude	E longitude
1	Chengamanad	10°9’20.8634”	76°19’16.7210”
2	Chengamanad	10°9’14.5026”	76°20’58.3839”
3	Chengamanad	10°7’20.4067”	76°22’0.0267”
4	Chengamanad	10°7’20.4057”	76°22’0.0265”
5	Sreemoolanagaram	10°8’22.3900”	76°23’58.0736”
6	Sreemoolanagaram	10°8’8.5527”	76°24’13.464”
7	Sreemoolanagaram	10°8’22.5652”	76°24’22.2886”
8	Sreemoolanagaram	10°8’29.1422”	76°24’24.7604”
9	Sreemoolanagaram	10°8’8.0685”	76°24’22.1994”
10	Kanjoor	10°8’57.6178”	76°25’34.3531”
11	Kanjoor	10°8’17.0336”	76°25’1.6849”
12	Kanjoor	10°9’24.8587”	76°25’41.3655”
13	Kanjoor	10°8’17.0336”	76°25’1.417”
14	Kanjoor	10°8’15.855”	76°25’1.93764”
15	Kalady	10°10’13.2931”	76°26’53.8429”
16	Kalady	10°10’33.816”	76°26’53.5336”
17	Kalady	10°10’26.8312”	76°26’21.2305”
18	Kalady	10°10’0.6974”	76°26’12.8997”
19	Kalady	10°10’18.2672”	76°25’17.4”
20	Kalady	10°10’41.3904”	76°25’49.6488”
21	Karukutty	10°17’50.7350”	76°20’14.811”
22	Karukutty	10°13’40.1885”	76°23’13.0431”
23	Karukutty	10°13’40.1885”	76°23’13.0431”
24	Karukutty	10°14’6.4154”	76°23’19.2850”
25	Parakkadav	10°11’35.5624”	76°20’31.8919”
26	Parakkadav	10°11’35.56248”	76°20’31.89192”
27	Parakkadav	10°11’10.2991”	76°20’30.4513”
28	Parakkadav	10°11’31.3194”	76°20’38.6980”

29	Parakkadav	10°11’30.2745”	76°20’29.1456”
30	Parakkadav	10°12’13.8326”	76°16’35.5994”
31	Parakkadav	10°12’14.0961”	76°16’35.6886”
32	Aluva	10°10’21.1213”	76°17’54.9445”
33	Aluva	10°10’21.3264”	76°17’54.6936”
34	Aluva	10°10’21.4756”	76°17’54.1070”
35	Karumaloor	10°9’47.5434”	76°15’3.97819”
36	Karumaloor	10°9’54.1418”	76°14’59.4827”
37	Karumaloor	10°11’14.2991”	76°14’8.1328”
38	Karumaloor	10°11’16.2413”	76°14’16.9924”
39	Karumaloor	10°10’13.6948”	76°14’2.2462”
40	Kunnukara	10°10’9.8778”	76°16’29.1277”
41	Kunnukara	10°12’20.7597”	76°17’46.5648”
42	Kunnukara	10°12’22.2023”	76°17’41.5132”
43	Kunnukara	10°12’18.8833”	76°17’42.7419”
44	Kunnukara	10°12’17.7287”	76°17’42.4679”
45	Choornikkara	10°9’47.0705”	76°12’40.2716”
46	Choornikkara	10°9’51.3601”	76°12’21.2155”
47	Choornikkara	10°10’8.7672”	76°12’34.4793”
48	Choornikkara	10°9’51.36012”	76°12’21.21552”
49	Choornikkara	10°10’10.3728”	76°11’38.8137”
50	Alangad	10°7’11.05522”	76°17’51.14505”
51	Alangad	10°7’14.1386”	76°17’45.2561”
52	Alangad	10°6’51.6711”	76°17’8.9286”
53	Alangad	10°7’2.5879”	76°17’0.1893”
54	Alangad	10°7’30.8816”	76°16’53.1776”
55	Edathala	10°4’48.6066”	76°16’5.3628”
56	Edathala	10°4’45.1674”	76°15’56.0207”
57	Edathala	10°7’10.9574”	76°17’10.8398”
58	Edathala	10°4’43.941”	76°16’28.5409”
59	Edathala	10°4’44.0889”	76°16’32.1567”

60	Edathala	10°4’47.6360”	76°16’53.9367”
61	Edathala	10°4’36.2654”	76°16’42.213”
62	Alangad	10°5’31.7576”	76°16’35.2444”
63	Alangad	10°5’25.2027”	76°16’17.6365”
64	Alangad	10°5’43.1844”	76°16’29.2106”

Table 3: Area and number of samples collected from each panchyats in AEU 5

Panchayat	Area (Sq.Km)	No. of samples collected
Kadamakkudy	10.14	3
Varapuzha	10.15	3
Kottuvally	20.82	3
Chittatukkara	11.98	2
Ezhikkara	15.27	2
Mulavukad	19.27	2
Elamkunnapuzha	11.52	2
Njarakkal	8.63	2
Nayarambalam	12.32	2
Puthenvelikkara	19.87	2
Edavanakkad	10.17	3
Kuzhuppilly	5.76	2
Pallippuram	16.5	2
Chendamangalam	10.72	3
Vadakekkara	9.32	3

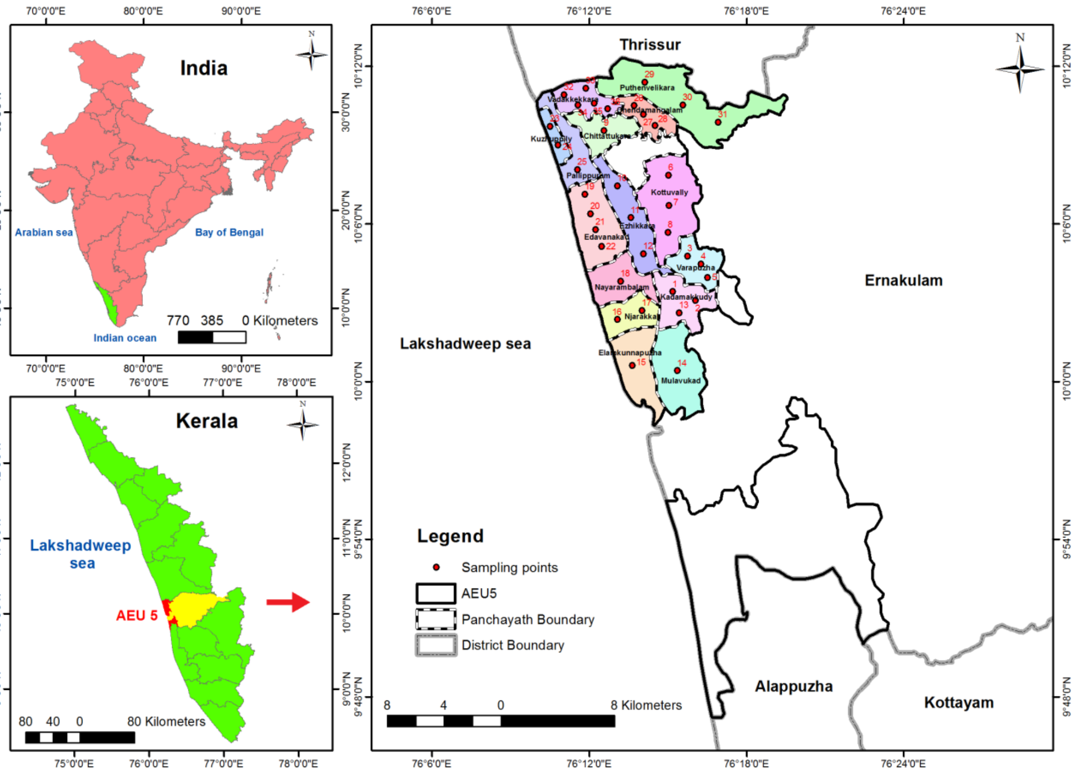

Plate 1. Location of study area in AEU 5

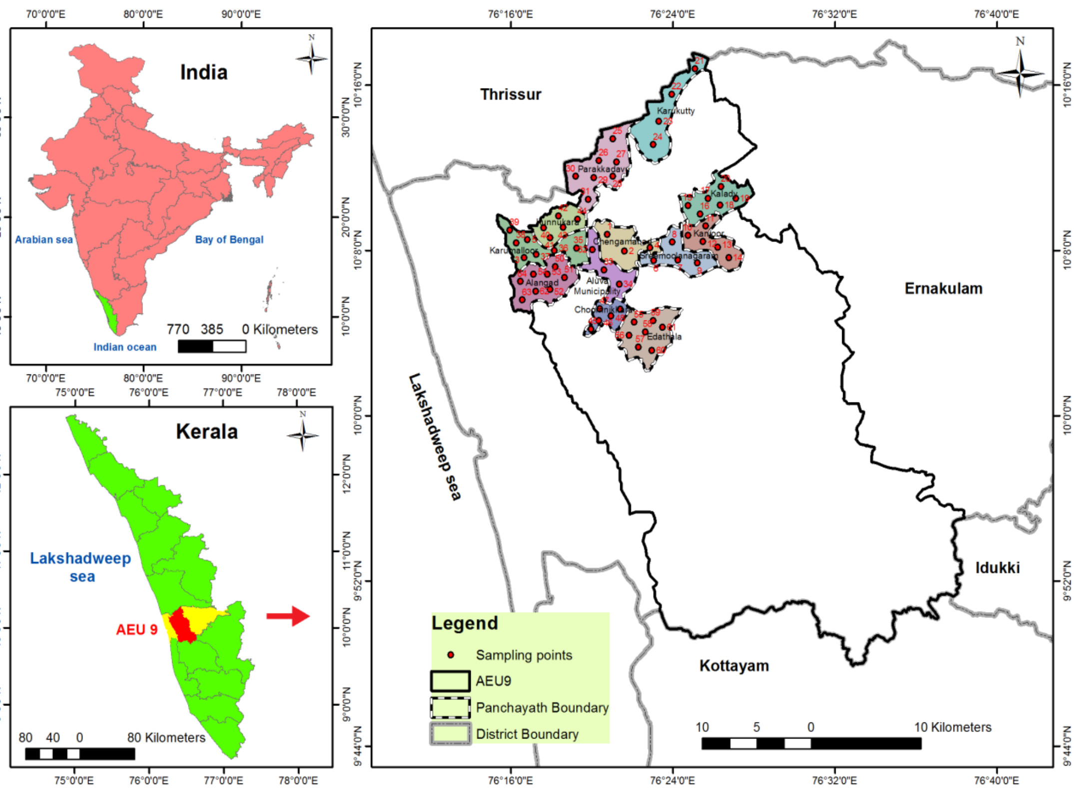

Plate 2. Location of study area in AEU 9

Plate 3: ***Pokkali*** **fields (AEU 5)**

Plate 4: ***Pokkali*** **fields (AEU 5)**

Plate 5: Homestead garden (AEU 9)

Plate 6: Arecanut field (AEU 9)

Table 4: Area and number of samples collected from each panchyats in AEU 9

Panchayat	Area (Sq.Km)	No. of samples collected
Chengamanad	15.59	4
Sreemoolanagaram	14.41	5
Kanjoor	14.32	5
Kalady	16.68	6
Karukutty	33.57	4
Parakkadav	24.66	7
Aluva	17.85	3
Karumaloor	21.5	5
Kunnukara	21.25	5
Choornikkara	11.07	5
Alangad	17.85	10
Edathala	15.98	7

3.4. CHARACTERIZATION OF SOIL SAMPLES

Soil samples collected from geo-referenced sites were analysed for physical, chemical and biological attributes. Wet analysis was followed in soil samples collected from AEU 5 by keeping the samples for moisture determination and remaining samples were analysed by dry analysis.

3.4.1. Physical attributes

3.4.1.1. Bulk density

Soil samples were collected using core sampler at a depth of 0-15 cm. These samples were dried to a constant weight in hot air oven at 105°C. The ratio of the mass of the dry soil to the total volume of soil was recorded as bulk density of sample (Dakshinamurti and Gupta, 1968, Blake and Hartge, 1986)

3.4.1.2. Particle density

Particle density of the given soil was estimated in the laboratory using Keen-Raczkowski (KR) box method (Keen and Raczkowski, 1921).

3.4.1.3. Porosity

Porosity was calculated using bulk density and particle density with the formula:

Porosity = (1 - BD/PD)

where, BD = Bulk density of soil (Mg m^{-3})

PD = Particle density of soil (Mg m^{-3})

3.4.1.5. Maximum water holding capacity

Maximum water holding capacity of the given soil was estimated using KR box method (Keen and Raczkowski, 1921). Filter paper was placed at the bottom of KR box and it was filled with dry soil. Then it was weighed and placed in a water bath. The change in weight was noted after when it was completely wetted.

3.4.1.6. Soil moisture content

Soil moisture content of the given soil was estimated using gravimetric method. The soil sample was weighed before and after drying in oven. Then the change in weight was calculated.

3.4.2. Chemical attributes

3.4.2.1. pH

Soil reaction was measured by pH meter, after equilibrating the soil with water in the ratio of 1:2.5 soil:water suspension (Jackson, 1958).

3.4.2.2. Electrical conductivity

Salt concentration in soil samples was measured by conductivity meter. The supernatant of soil water suspension used for pH estimation (Jackson, 1958).

3.4.2.3. Effective cation exchange capacity

Effective cation exchange capacity was calculated using the formula given by Reeuwijk (2002):

ECEC = Exchangeable (Na+ K+ Ca+ Mg+ acidity)

3.4.2.4. Exchangeable acidity

The method used for estimation of exchangeable acidity is the modified form of Reeuwijk (2002). The soil samples were extracted with 1M KCl solution and titrated with 0.01M NaOH.

3.4.2.5. Available nitrogen

Available nitrogen (N) was estimated using alkaline potassium permanganate method using Kelplus distillation system (Subbiah and Asija, 1956). Alkaline potassium permanganate oxidises organic matter present in the soil and hydrolyses the liberated ammonia. Ammonia liberated was condensed and absorbed in boric acid mixed indicator and it was titrated against standard acid.

3.4.2.6. Available phosphorus

Available phosphorus (P) in soil samples was determined by Bray method. Soil samples were extracted using Bray No.1 reagent (Bray and Kurtz, 1945). It was estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965) using spectrophotometer at 660nm.

3.4.2.7. Available potassium

Available potassium (K) in soil samples was determined by flame photometer using neutral normal ammonium acetate as an extractant (Jackson, 1958).

3.4.2.8. Available calcium and magnesium

Available calcium (Ca) and magnesium (Mg) in the soil samples were extracted using neutral normal ammonium acetate and concentration of calcium and magnesium in the extract was measured using atomic absorption spectrophotometer (Jackson, 1958).

3.4.2.9. Available sulphur

Available sulphur (S) in the soil samples was extracted using 0.15% $CaCl_2$ solution (Tabatabai,1982) and the concentration of S in the extract was measured using spectrophotometer at 440nm using the principle of turbidimetry with Barium chloride crystals of uniform size (Massoumi and Cornfield, 1963).

3.4.2.10. Available micronutrients

Available micronutrients in soil samples were extracted using 0.1N HCl. The extract was used to analyse iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) using atomic absorption spectrophotometer (Sims and Johnson, 1991).

3.4.2.11. Available boron

Available boron (B) in the soil samples was extracted using hot water and estimated colorimetrically by azomethine – H using spectrophotometer at 420 nm (Gupta, 1967).

3.4.3. Biological attributes

3.4.3.1. Organic carbon

Organic carbon content of the soil sample was estimated by Walkley and Black method or wet digestion method (Walkley and Black, 1934). Air dried soil samples of 0.5 mm mesh size were oxidised with 0.5 N potassium dichromate in presence of concentrated sulphuric acid, the amount of potassium dichromate unreacted is back titrated with 0.5 N ferrous ammonium sulphate using ferroin indicator.

3.4.3.2. Dehydrogenase activity

Dehydrogenase activity was estimated colorimetrically using spectrophotometer. Fresh soil sample was treated with 0.1 per cent 2, 3, 5-

triphenyltetrazolium chloride (TTC) and 0.25 per cent glucose solution and incubated for 24 hrs. In this process, TTC gets reduced to a pink coloured compound triphenyl formazon (TPF) which was extracted quantitatively by methanol and measured colorimetrically (Cassida *et al.*, 1964, Page *et al.*, 1982).

3.4.3.3. Microbial biomass carbon

Chloroform fumigation and extraction method was used for estimation of microbial biomass carbon. Five sets of sample each of 10g were taken and two sets were kept in vacuum dessicator containing ethanol free choloroform for 24 hrs incubation under vacuum condition. One set was kept in oven at 105°C for determination of moisture gravimetrically. After incubation organic carbon was extracted from the fumigated and non-fumigated samples using 0.5 M K_2SO_4. To 10 ml of this extract, 2 ml potassium dichromate, 5 ml orthophosphoric acid and 10 ml concentrated sulphuric acid were added and kept in hot plate at 100°C for 30 minutes under reflux. Then 200 ml water was added after refluxing to stop the reaction and titrated against ferrous ammonium sulphate (Jenkinson and Pawlson, 1976).

3.5. STATISTICAL ANALYSIS

Measured data was analysed by Duncan's multiple range test (MRT) using SPSS software and statistical significance of each panchayats were examined. Arithmetic mean was calculated for each panchayats. Correlation analysis was performed for the physical, chemical and biological attributes and correlation between the attributes were analysed.

3.6. SOIL QUALITY INDEX ASSESSMENT

Soil quality assessment was done by the method described by Andrews *et al.* (2002). There are three main steps involved in the soil quality index method which includes (i) selection of a minimum data set (MDS) of indicators which includes the most significant variables that best represent the soil functions (ii) development of the MDS indicators and scores are given to each indicators (iii) integration of the indicator scores and calculation of index of soil quality.

Principal component analysis (PCA) was performed for soil attributes to develop MDS. The principle components (PCs) with higher values best represent the systems, the PCs having eigen value more than 1 was selected. MDS was developed by selecting the PCs. After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods (Andrews *et al.,* 2002). Three types of scoring curves were used: i) *more is better*, ii) *less is better*, iii) *optimum* curve (Bastida *et al.*, 2006; Raiesi, 2017). For non-linear scoring, the following sigmoidal function is used

$S_{NL} = a/1+(X/X_m)^b$

where S_{NL} is the non-linear score of the soil indicator, a is the maximum score reached by the function which is equal to 1, X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation and is set as −2.5 for a "*more is better*" curve and 2.5 for a "*less is better*" curve.

Soil quality index (SQI) was calculated using the method described by Doran and Parkin (1994):

Soil quality index = $\sum_{i=1}^{n} Wi \times Si$

where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA.

The change in soil quality was measured by relative soil quality index (RSQI) and was calculated using the method given by Karlen and Scott, (1994).

RSQI = computed SQI / theoretical maximum SQI × 100

where computed SQI is the value of each soil variable and theoretical maximum SQI is maximum SQI obtained by calculating with maximum score of each variable. RSQI values <50% is categorized as poor, 50-70 % as medium and >70% is categorized as good.

3.7. NUTRIENT INDEX

The nutrient index in the soil was calculated for the soil samples using the following formula given by Ravikumar and Somashekar, (2013).

$$\text{Nutrient index} = (1\times L) + (2 \times M) + (3 \times H) / N$$

where L is the number of samples in low category, M is the number of samples in medium category, H is the number of samples in high category and N is the total number of samples. The nutrient index value greater than 2.33 is rated as high, 1.67-2.33 is rated as medium and less than 1.67 is rated as low category.

3.8. PREPARATION OF GIS MAPS

The soil parameters and RSQI value generated after the soil quality assessment of the soil samples collected from different locations were used for the preparation of geo-referenced thematic maps using ArcGIS software.

Results

RESULTS

The present study consisted of analysis of various physical, chemical and biological parameters. The analytical data generated were subjected to statistical analysis and soil quality index, relative soil quality index were worked out and the experimental results are presented below.

4.1. PHYSICAL ATTRIBUTES

Analysis for different physical properties were done for the post flood soil samples collected from different sites of AEU 5 and 9 of Ernakulam district. Soil samples were analysed for different physical properties such as bulk density, particle density, porosity, maximum water holding capacity and soil moisture content.

4.1.1. Bulk density

The bulk density of the post flood soils of AEU 5 ranged from 0.23 Mg m^{-3} in Kadamakkudy to 1.53 Mg m^{-3} in Vadakkekkara (uplands). Among different panchayats, highest mean was observed in Vadakkekkara uplands (1.30 Mg m^{-3}) and lowest mean was found in Elamkunnapuzha (0.38 Mg m^{-3}) (Table 5). Bulk density was negatively correlated to organic carbon (r= -0.381*), available Ca (r= -0.527**), available Mg (r= -0.539**), available S (r= -0.441*), effective cation exchange capacity (r= -0.566**), porosity (r= -0.940**), water holding capacity (r= -0.626**) and soil moisture (r= -0.622**) (Appendix II).

In the post flood soils of AEU 9, bulk density ranged from 0.89 Mg m^{-3} in Kalady to 1.73 Mg m^{-3} in Karukutty. Among the panchayats highest mean recorded was 1.50 Mg m^{-3} at Karukutty and lowest mean was observed in Sreemoolanagaram (1.22 Mg m^{-3}) (Table 6). Bulk density recorded a significant negative correlation with organic carbon (r= -0.319*), available S (r= -0.290*), available Fe (r= -0.277*), exchangeable acidity (r= -0.289*), porosity (r= -0.927**), maximum water holding capacity (r= -0. 292*) and soil moisture (r= -0. 363**) (Appendix II).

4.1.2. Particle density

The particle density of post flood soils varied from 2.06 Mg m^{-3} in Varapuzha to 2.85 Mg m^{-3} in Vadakkekkara (uplands) under AEU 5 of Ernakulam district. The lowest mean was recorded in Varapuzha (2.16 Mg m^{-3}) and highest mean was recorded in Chendamangalam (uplands) (2.76 Mg m^{-3}) (Table 5). Particle density varied significantly among different panchayats and also showed a significant negative correlation with organic carbon (r= -0.364*), available N (r = -0.521**), available Ca (r= -0.418*), available Mg (r= -0.472*), effective cation exchange capacity (r= -0.566**), water holding capacity (r= -0.481*) and soil moisture (r= -0.547**) (Appendix II).

In AEU 9 particle density varied from 2.21 Mg m^{-3} in Chengamanad to 2.85 Mg m^{-3} in Choornikkara. The lowest mean was recorded in Sreemoolanagaram (2.47 Mg m^{-3}) and highest mean was recorded in Karumaloor (2.74 Mg m^{-3}) (Table 6). Similar to AEU 5, particle density of soil in AEU 9 also varied significantly among different panchayats. Further, it showed significant negative correlation with organic carbon (r= -0.122*), available N (r= -0.259*), soil moisture (r= 0.344**), available B (r= -0.307**) and significant positive correlation with dehydrogenase activity (r=0.301**), available Mn (r= 0.236*) and porosity (r= -0.352**). (Appendix II).

4.1.3. Porosity

Considering the porosity of the post flood soils under AEU 5, the highest mean was recorded in Elamkunnapuzha (85.94 %) and lowest mean was recorded in Vadakkekkara (uplands) (51.52 %) (Table 5). It ranged from 42.98 per cent in Vadakkekkara (uplands) to 89.07 per cent in Kadamakkudy. A significant positive correlation with organic carbon (0.244*), available Ca (r= 0.405*), water holding capacity (r= 0.471*) and soil moisture (r= 0.446*) and significant negative correlation with bulk density (r= -0.940**) was observed for porosity (Appendix II).

In AEU 9, the highest mean was recorded in Karumaloor (52.93%) and the lowest mean was recorded in Karukutty (38.54%) (Table 6). The porosity of the soil samples ranged from 29.29 per cent in Karukutty to 63.60 per cent in Kalady. A significant positive correlation with organic carbon (r= 0.124*), available S (r= 0.328**), available Fe (r= 0.334**), exchangeable acidity (r= 0.246*), particle density (r=0.344**) and water holding capacity (r= 0. 291*) and significant negative correlation with bulk density (r= -0.927**) was observed for porosity (Appendix II).

4.1.4. Maximum water holding capacity

Under AEU 5, the highest mean in water holding capacity of the post flood soils was recorded as 80.37 per cent in Elamkunnapuzha and the lowest mean was recorded as 35.50 per cent in Vadakkekkara (Table 7). It ranged from 23.05 per cent in Vadakkekkara (uplands) to 88.6 per cent in Chittatukkara. Organic carbon (r= 0.271*), dehydrogenase activity (r= 0.584**), available N (r= 0.690**), available P (r= 0.532**), available Ca (r= 0.851**), available Mg (r= 0.905**), available S (r= 0.644**), available B (r= 0.490*), effective cation exchange capacity (r= 0.916**), porosity (r= 0.471*) and soil moisture (r= 0.446*) were significantly positively correlated and particle density (r= -0.481*) and bulk density (r= -0.626**) were significantly negatively correlated with maximum water holding capacity (Appendix II).

In the post flood soils, highest mean was recorded as 42.86 per cent in Kunnukara and the lowest mean was recorded as 33.2 per cent in Parakkadav under AEU 9 (Table 8). It varied from 27.51 per cent in Aluva to 49.91 per cent in Kunnukara. Water holding capacity varied significantly among different panchayats. It had a significant positive correlation with organic carbon (r= 0.147*), available K (r= 0.253*), available S (r= 0.506**), available Mg (r= 0.269*), available Fe (r= 0.233*), available Mn (r= 0.366**), effective cation exchange capacity (r= 0.301**), porosity (r= 0.291*) and soil moisture (r= 0.262*) and significant negative correlation with bulk density (r= -0.292*) and available P (r= -0.322**) (Appendix II).

4.1.5. Soil moisture content

The soil moisture content varied from 9.50 per cent in Chendamangalam (uplands) to 67.4 per cent in Varapuzha in the post flood soils of AEU 5. The highest mean was observed in Varapuzha (59.83%) and the lowest mean was observed in Chendamangalam (uplands) (19.26%) (Table 7). A significant positive correlation with dehydrogenase activity (r= 0.474*), available N (r= 0.740**), available P (r= 0.539**), available Ca (r= 0.791**), available Mg (r= 0.960**), available S (r= 0.748**), available Zn (r= 0.437*), available B (r= 0.562**), effective cation exchange capacity (r= 0.952**), water holding capacity (r= 0.890**) and porosity (r= 0.446*) and negative correlation with bulk density (r= -0.622**) and particle density (r= -0.547**) was observed for soil moisture (Appendix II).

The soil moisture content varied from 2.03 per cent in Alangad to 36.85 per cent in Kanjoor under AEU 9. The highest mean was observed in Chengamanad (24.53%) and lowest mean was observed in Edathala (10.30%) (Table 8). It differed significantly among different panchayats. A significant positive correlation with available N (r= 0.310**), available Mn (r= 0.235*), effective cation exchange capacity(r= 0.306**) and water holding capacity (r= 0.262*) and significant negative correlation with available Zn (r= -0.254*), bulk density (r= -0.363**) and particle density (r= -0.352**) was observed for soil moisture (Appendix II).

Table 5. Mean, standard deviation and range of bulk density, particle density and porosity of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	0.39 ± 0.13	0.23 - 0.49	2.21 ± 0.07	2.16 - 2.30	82.46 ± 5.76	78.51 - 89.07
Varapuzha	0.43 ± 0.05	0.38 - 0.49	2.16 ± 0.13	2.01 - 2.24	79.89 ± 1.58	78.09 - 81.04
Kottuvally	0.5 ± 0.25	0.30 - 0.79	2.44 ± 0.09	2.34 - 2.52	80.22 ± 10.21	68.45 - 86.82
Chittatukkara	0.66 ± 0.36	0.51 - 0.73	2.20 ± 0.23	2.12 - 2.35	73.64 ± 1.20	70.96 - 78.66
Ezhikkara	0.45 ± 0.08	0.37 - 0.54	2.31 ± 0.13	2.16 - 2.44	80.51 ± 2.65	77.61 - 82.81
Mulavukad	0.61 ± 0.27	0.30 - 0.78	2.20 ± 0.13	2.13 - 2.38	73.01 ± 1.36	71.36 - 79.55
Elamkunnapuzha	0.38 ± 0.45	0.23 - 0.45	2.29 ± 0.11	2.26 - 2.45	85.94 ± 3.78	79.65 - 89.23
Njarakkal	0.47 ± 0.22	0.31 - 0.63	2.46 ± 0.36	2.20 - 2.62	79.71 ± 12.21	71.08 - 88.34
Nayarambalam	0.55 ± 0.45	0.36 - 0.60	2.55 ± 0.05	2.46 - 2.66	80.51 ± 2.98	75.32 - 85.21
Puthenvelikkara	0.45 ± 0.02	0.43 - 0.47	2.43 ± 0.03	2.40 - 2.45	81.12 ± 1.40	80.13- 82.12
Edavanakkad	0.45 ± 0.06	0.41 - 0.50	2.38 ± 0.32	2.15 - 2.61	80.45 ± 5.47	76.58 - 84.32
Kuzhuppilly	0.51 ± 0.10	0.44 - 0.58	2.19 ± 0.02	2.17 - 2.21	76.66 ± 4.30	73.62 - 79.71
Pallippuram	0.57 ± 0.21	0.40 - 0.59	2.56 ± 0.21	2.59 - 2.60	70.99 ± 5.46	65.01 - 75.68
Chendamangalam	1.12 ± 0.27	0.77 - 1.37	2.76 ± 0.09	2.61 - 2.82	59.19 ± 10.22	44.97 - 72.01
Vadakekkara	1.30 ± 0.15	1.11 - 1.53	2.68 ± 0.10	2.60 - 2.85	51.52 ± 5.48	42.98 - 57.57

Table 6. Mean, standard deviation and range of bulk density, particle density and porosity of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	1.28 ± 0.21	1.08 - 1.54	2.56 ± 0.08	2.45 - 2.65	50.04 ± 7.94	39.57-58.26
Sreemoolanagaram	1.22 ± 0.17	1.07 - 1.51	2.47 ± 0.21	2.21 - 2.79	49.68 ± 6.63	40.49 - 55.41
Kanjoor	1.35 ± 0.09	1.25 - 1.48	2.51 ± 0.13	2.27 - 2.61	46.01 ± 5.86	38.02 - 51.95
Kalady	1.23 ± 0.24	0.89 - 1.49	2.58 ± 0.22	2.31 - 2.92	52.19 ± 8.70	40.59 - 63.60
Karukutty	1.50 ± 0.16	1.34 - 1.73	2.57 ± 0.08	2.45 - 2.63	38.54 ± 41.56	29.29 - 48.81
Parakkadav	1.34 ± 0.14	1.16 - 1.54	2.57 ± 0.10	2.39 - 2.67	47.67 ± 6.49	39.91 - 57.26
Aluva	1.29 ± 0.17	1.10 - 1.45	2.66 ± 0.07	2.57 - 2.70	51.46 ± 6.67	46.19 - 58.97
Karumaloor	1.29 ± 0.21	1.09 - 1.62	2.74 ± 0.06	2.65 - 2.82	52.93 ± 6.92	42.33 - 59.43
Kunnukara	1.40 ± 0.15	1.30 - 1.67	2.71 ± 0.09	2.61 - 2.82	47.98 ± 7.04	36.15 - 53.55
Choornikkara	1.30 ± 0.12	1.09 - 1.40	2.66 ± 0.11	2.57 - 2.85	51.17 ± 4.36	46.03 - 57.40
Alangad	1.36 ± 0.15	1.19 - 1.64	2.67 ± 0.05	2.59 - 2.77	48.88 ± 5.73	38.79 - 56.83
Edathala	1.29 ± 0.10	1.11 - 1.40	2.67 ± 0.13	2.53 - 2.76	51.57 ± 3.80	47.88 - 58.40

Table 7. Mean, standard deviation and range of maximum water holding capacity and soil moisture content of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Maximum water holding capacity (%)		Soil moisture content (%)	
	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	77.99 ± 66.53	64.96 - 84.63	47.83 ± 14.03	36.7 - 63.6
Varapuzha	65.93 ± 74.47	52.39 - 78.30	59.83 ± 7.22	53 - 67.4
Kottuvally	70.73 ± 55.13	33.89 - 83.98	44.13 ± 17.13	25.6 - 59.4
Chittatukkara	58.13 ± 28.79	43.29 - 88.6	38.7 ± 12.56	25.3 - 62.98
Ezhikkara	57.47 ± 27.49	47.82 - 82.12	43.4 ± 6.63	37.2 - 50.4
Mulavukad	60.32 ± 33.2	49.65 - 73.65	38.3 ± 10.25	27.6 - 59.86
Elamkunnapuzha	80.37 ± 45.6	51.29 - 85.64	44.9 ± 7.84	36.54 - 52.14
Njarakkal	62.37 ± 27.99	42.57 - 75.16	56.5 ± 12.16	47.9 - 65.1
Nayarambalam	59.70 ± 25.61	42.13 - 96.3	33.7 ± 8.43	23.65 - 42.15
Puthenvelikkara	75.92 ± 2.11	60.43 - 83.42	55.25 ± 2.89	53.2 - 57.3
Edavanakkad	66.54 ± 6.52	51.92 - 81.16	50.25 ± 5.58	46.3 - 54.2
Kuzhuppilly	64.91 ± 5.77	50.83 - 119	47 ± 2.54	45.2 - 48.8
Pallippuram	58.11 ± 28.94	49.87 - 73.5	31.8 ± 7.65	22.15 - 48.65
Chendamangalam	46.18 ± 12.97	31.16 - 58.74	19.26 ± 7.64	9.50 - 30.73
Vadakekkara	35.50 ± 8.55	23.05 - 44.78	19.67 ± 5.51	14.57 - 28.87

Table 8. Mean, standard deviation and range of maximum water holding capacity and soil moisture content of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	Maximum water holding capacity (%)		Soil moisture content (%)	
	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	$40.69^{bcd} \pm 2.24$	39.45 - 44.05	$24.53^{a} \pm 7.007$	17.49 - 31.36
Sreemoolanagaram	$39.27^{bcde} \pm 7.14$	27.63 - 45.62	$20.79^{ab} \pm 12.85$	3.29 - 34.69
Kanjoor	$41.64^{bc} \pm 5.79$	35.83 - 49.92	$23.82^{ab} \pm 7.90$	16.88 - 36.85
Kalady	$34.65^{cde} \pm 8.04$	23.96 - 42.59	$22.79^{ab} \pm 7.94$	15.8 - 34.75
Karukutty	$33.73^{de} \pm 7.31$	25.26 - 42.88	$16.32^{bc} \pm 2.83$	12.24 - 18.63
Parakkadav	$33.22^{e} \pm 5.65$	28.77 - 45.11	$21.15^{ab} \pm 9.32$	12.45 - 35.36
Aluva	$37.81^{bcde} \pm 11.19$	27.51 - 49.72	$20.71^{ab} \pm 3.38$	17.36 - 24.13
Karumaloor	$39.56^{a} \pm 5.94$	32.90 - 48.80	$23.14^{ab} \pm 4.66$	19.31 - 30.02
Kunnukara	$42.86^{b} \pm 3.80$	37.34 - 47.91	$20.10^{ab} \pm 5.94$	10.91 - 25.83
Choornikkara	$37.16^{bcde} \pm 2.78$	32.57 - 39.78	$17.78^{abc} \pm 8.30$	9.61 -30.13
Alangad	$36.63^{bcde} \pm 6.83$	27.65 - 49.46	$11.26^{c} \pm 5.28$	2.03 - 17.65
Edathala	$36.45^{de} \pm 5.33$	31.11 - 44.64	$10.30^{c} \pm 4.04$	4.73 - 14.63

4.2. CHEMICAL ATTRIBUTES

4.2.1. Soil reaction

The soil pH varied from 3.04 in Ezhikkara to 7.22 in Kadamakkudy in the post flood soils of AEU 5. The highest mean was noticed in Nayarambalam (6.9) and lowest mean was noticed in Ezhikkara (4.1) (Table 9). The pH of soils showed significant difference among different panchayats. Further, pH of soils were significantly positively correlated with dehydrogenase activity (r= 0.521**), available Fe (r= 0.545**) and exchangeable acidity (r= 0.605**) whereas, available N had significant negative correlation with the pH (r= -0.544**) (Appendix II).

In AEU 9, the soil pH varied from 5.01 in Choornikkara to 7.69 in Kanjoor. The highest mean was noticed in Kanjoor (6.38) and lowest mean was noticed in Sreemoolanagaram (5.02) (Table 10). The pH of soils showed significant difference among different panchayats. A significant positive correlation with available Ca (r= 0.631**), available Mg (r= 0.338**), available Zn (r= 0.231*) and effective cation exchange capacity (r= 0.468**) and significant negative correlation with exchangeable acidity (r= -0.274*) was recorded for soil pH (Appendix II).

4.2.2. Electrical Conductivity

The electrical conductivity (EC) values of the soils ranged from 0.19 dS m^{-1} in Chendamangalam (uplands) to 7.72 dS m^{-1} in Njarakkal under AEU 5. The highest mean value recorded was 7.2 dS m^{-1} in Njarakkal and the lowest mean value recorded was 0.47 dS m^{-1} in Vadakkekkara (uplands) (Table 9). Correlation analysis showed that electrical conductivity were significantly positively correlation with available Cu (r= 0.426*) and organic carbon (r= 0.411*) (Appendix II).

The electrical conductivity (EC) values of the soil samples ranged from 0.011 dS m^{-1} in Chengamanad and Parakkadav to 0.056 dS m^{-1} in Kunnukara under AEU 9. The highest mean value recorded was 0.034 dS m^{-1} in Alangad and Sreemoolanagaram and the lowest mean value recorded was 0.017 dS m^{-1} in Karumaloor (Table 10). The electrical conductivity was not significantly different among panchayats. In correlation analysis, electrical conductivity did not show any correlation with other parameters.

4.2.3. Exchangeable acidity

The lowest mean value of exchangeable acidity recorded was 0.013 cmol(+)kg^{-1} in Varapuzha and highest mean value recorded was 1.38 cmol(+)kg^{-1} in Chendamangalam (uplands) under AEU 5 (Table 11) and ranged from 0.010 cmol(+)kg^{-1} in Varapuzha to 3.33 cmol(+)kg^{-1} in Chendamangalam (uplands). In correlation analysis, a significant negative correlation was noticed with available K (r= -0.428*) and pH (r = -0.605**) (Appendix II).

In AEU 9, highest mean value of exchangeable acidity recorded was 0.78 cmol(+)kg^{-1} in Karukutty and the lowest mean value recorded was 0.08 cmol(+)kg^{-1} in Kalady with a range of 0.13 cmol(+)kg^{-1} in Parakkadav to 2.866 cmol(+)kg^{-1} in Sreemoolanagaram (Table 12). Exchangeable acidity showed significant difference among different panchayats. In correlation analysis, exchangeable acidity showed significant negative correlation with available Ca (r = -0.308**), available Mg (r= -0.393**), pH (r = -0.274*) and bulk density (r = -0.289*) and significant positive correlation with available S (r = 0.370**) and porosity (r= 0.246*) (Appendix II).

4.2.4. Effective cation exchange capacity

The effective cation exchange capacity of the post flood soils ranged from 9.41 cmol(+)kg^{-1} in Chendamangalam (uplands) to 71.32 cmol(+)kg^{-1} in Varapuzha under AEU 5 of Ernakulam district. Highest mean was observed in Varapuzha (59.30 cmol(+)kg^{-1}) and lowest mean was observed in Chendamangalam (uplands) (12.70 cmol(+)kg^{-1}) (Table 11). A significant positive correlation with dehydrogenase activity (r= 0.521**), available N (r= 0.711**), available P (r= 0.543**), available Ca (r= 0.838**), available Mg (r= 0.969**), available S (r= 0.702**), available Zn (r= 0.429*), available B (r= 0.573**), water holding capacity (r= 0.916**) and soil moisture (r= 0.952**) and negative correlation with bulk density (r= -0. 545**) and particle density (r= -0. 566**) was observed (Appendix II).

In the post flood soils of AEU 9, the lowest value recorded was 9.24 cmol(+)kg^{-1} in Aluva and the highest value recorded was 18.91 cmol(+)kg^{-1} in Kalady and highest mean was observed in Kalady (14.38 cmol(+)kg^{-1}) and lowest mean was observed in Chengamanad (10.91 cmol(+)kg^{-1}) (Table 12). It varied significantly among different panchayats. A significant positive correlation with available Ca (r= 0.802**), available Mg (r= 0.497**), available Mn (r= 0.385**), available Zn (r= 0.361**), pH (r= 0.468**), water holding capacity (r= 0.301**) and soil moisture (r= 0.306**) and significant negative correlation with available K (r= -0.242*) was observed (Appendix II).

Table 9. Mean, standard deviation and range of soil reaction and electrical conductivity of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	pH		Electrical conductivity (dS m^{-1})	
	Mean ± SD	Range	Mean± SD	Range
Kadamakkudy	6.73^{ab} ± 0.42	6.46 - 7.22	4.21 ± 2.83	1.8 - 7.3
Varapuzha	5.09^{b} ± 1.15	3.81 - 6.05	5 ± 1.85	2.9 - 6.4
Kottuvally	5.36^{ab} ± 0.30	5.03 - 5.64	5.56 ± 3.45	3.08 - 9.5
Chittatukkara	6.02^{c} ± 1.01	5.5 - 6.12	1.88 ± 2.36	1.03 - 2.98
Ezhikkara	4.1^{ab} ± 1.64	3.04 - 5.99	6.5 ± 1.21	5.2 - 7.6
Mulavukad	7^{a} ± 0.23	6.5 - 7.09	3.3 ± 0.23	3.01 - 3.5
Elamkunnapuzha	5.29^{ab} ± 0.98	4.56 - 6.02	3.4 ± 0.18	3.1 - 3.8
Njarakkal	5.34^{ab} ± 1.76	4.09 - 6.59	7.2 ± 3.53	4.7 - 9.7
Nayarambalam	6.9^{a} ± 1.01	5.56 - 7.04	5.1 ± 2.6	4.5 - 6.8
Puthenvelikkara	6.75^{ab} ± 0.48	6.41 - 7.09	4.6 ± 3.81	1.9 - 7.3
Edavanakkad	6.01^{ab} ± 0.81	5.44 - 6.59	3.1 ± 0.42	2.8 - 3.4
Kuzhuppilly	6.77^{ab} ± 0.29	6.56 - 6.98	4.9 ± 0.70	4.4 - 5.4
Pallippuram	6.5^{ab} ± 0.65	6 - 7.1	6.1 ± 2.3	5.3 - 7.1
Chendamangalam	5.63^{bcd} ± 0.28	5.23 - 6.01	0.26 ± 0.039	0.19 - 0.03
Vadakekkara	5.08^{d} ± 0.57	4.36 - 5.83	0.47 ± 0.019	0.29 - 0.076

Table 10. Mean, standard deviation and range of soil reaction and electrical conductivity of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	pH		Electrical conductivity (dS m^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	5.43^{bcd} ± 0.41	5.03 - 6.01	0.022 ± 0.010	0.011 - 0.035
Sreemoolanagaram	5.02^{d} ± 0.47	4.41 - 5.61	0.034 ± 0.016	0.013 - 0.054
Kanjoor	6.38^{a} ± 0.84	5.73 - 7.69	0.032 ± 0.090	0.021 - 0.045
Kalady	6.35^{a} ± 0.73	5.52 - 7.5	0.026 ± 0.010	0.016 - 0.044
Karukutty	5.04^{d} ± 0.56	4.32 - 5.69	0.041 ± 0.010	0.029 - 0.049
Parakkadav	5.18^{cd} ± 0.56	4.47 - 5.89	0.029 ± 0.013	0.011 - 0.046
Aluva	5.51^{bcd} ± 0.71	4.91 - 6.3	0.027 ± 0.078	0.022 - 0.036
Karumaloor	5.43^{bc} ± 0.46	4.82 - 5.9	0.017 ± 0.024	0.014 - 0.02
Kunnukara	5.06^{d} ± 0.39	4.66 - 5.67	0.031 ± 0.015	0.015 - 0.056
Choornikkara	5.54^{bcd} ± 0.40	5.01 - 6.09	0.029 ± 0.010	0.015 - 0.041
Alangad	5.86^{cd} ± 0.55	5.04 - 6.7	0.034 ± 0.012	0.017 - 0.05
Edathala	5.31^{ab} ± 0.44	4.61 - 5.84	0.030 ± 0.013	0.013 - 0.05

Table 11. Mean, standard deviation and range of exchangeable acidity and effective cation exchange capacity of the post flood soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Exchangeable acidity (cmol(+)kg^{-1})		Effective cation exchange capacity (cmol(+)kg^{-1})	
	Mean ± SD	Range	Mean±SD	Range
Kadamakkudy	0.023 ± 0.013	0.012-0.037	42.60 ± 14.76	29.07 - 58.34
Varapuzha	0.013 ± 0.002	0.010-0.015	59.30 ± 12.39	46.56 - 71.32
Kottuvally	0.023 ± 0.004	0.017-0.027	41.27 ± 13.38	27.94 - 54.71
Chittatukkara	0.020 ± 0.003	0.019-0.025	33.30 ± 11.78	25.47 - 59.12
Ezhikkara	0.966 ± 0.915	0.062-1.89	37.87 ± 3.05	35.01 - 41.09
Mulavukad	0.047 ± 0.008	0.035-0.051	38.07 ± 12.65	25.64 - 51.23
Elamkunnapuzha	0.036 ± 0.007	0.023-0.049	37.42 ± 9.65	22.36 - 45.63
Njarakkal	0.037 ± 0.020	0.023-0.052	51.46 ± 10.68	43.9 - 59.02
Nayarambalam	0.044 ± 0.006	0.031-0.052	30.66 ± 13.68	25.64 - 48.23
Puthenvelikkara	0.052 ± 0.013	0.062-0.042	52.07 ± 5.65	48.08 - 56.07
Edavanakkad	0.040 ± 0.007	0.035-0.045	49.40 ± 9.29	42.82 - 55.97
Kuzhuppilly	0.053 ± 0.002	0.051-0.054	41.85 ± 2.50	40.07 - 43.62
Pallippuram	0.090 ± 0.890	0.062-1.62	46.17 ± 8.45	39.64 - 48.62
Chendamangalam	1.38 ± 1.33	0.066 - 3.33	12.70 ± 1.69	9.41 - 13.56
Vadakekkara	0.14 ± 0.17	0.066 - 0.466	15.25 ± 2.85	11.88 - 18.46

Table 12. Mean, standard deviation and range of exchangeable acidity and effective cation exchange capacity of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	Exchangeable acidity (cmol(+)kg^{-1})		Effective cation exchange capacity (cmol(+)kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	0.21 ± 0.17	0.066 - 0.46	10.91^{e} ± 0.83	10.24 - 11.99
Sreemoolanagaram	0.77 ± 1.17	0.16 - 2.86	11.67^{cde} ± 0.79	10.89 - 12.54
Kanjoor	0.24 ± 0.20	0.066 - 0.6	14.17^{ab} ± 2.67	10.73 - 17.74
Kalady	0.08 ± 0.03	0.066 - 0.13	14.38^{ab} ± 2.82	10.88 - 18.91
Karukutty	0.78 ± 0.49	0.2 - 1.33	11.39^{cde} ± 0.48	11.02 - 12.09
Parakkadav	0.56 ± 0.50	0.13 - 1.6	12.14^{bcde} ± 3.08	9.60 - 18.78
Aluva	0.28 ± 0.07	0.2 - 0.33	11.51^{cde} ± 3.03	9.24 - 14.96
Karumaloor	0.41 ± 0.70	0.066 - 1.66	12.74^{abcd} ± 2.06	10.24 - 15.97
Kunnukara	0.33 ± 0.55	0.066 - 1.33	12.51^{bcde} ± 0.70	11.83 - 13.36
Choornikkara	0.09 ± 0.03	0.066 - 0.13	13.54^{abc} ± 1.96	11.27 - 16.04
Alangad	0.39 ± 0.57	0.066 - 1.73	11.85^{de} ± 1.91	9.35 - 12.54
Edathala	0.24 ± 0.39	0.066 - 1.13	11.61^{bcde} ± 1.77	9.44 - 14.05

4.2.5. Available nitrogen

The highest available N was observed in Varapuzha (1616.09 kg ha^{-1}) and lowest value observed was 172.44 kg ha^{-1} in Mulavukad in the post flood soils of AEU 5. Highest mean was recorded as 1086.93 kg ha^{-1} in Varapuzha and lowest mean was recorded as 292.44 kg ha^{-1} in Mulavukad (Table 13). In correlation analysis it showed significant positive correlation with organic carbon (r= 0.568*), available P (r= 0.648**), available Ca (r= 0.676**), available Mg (r= 0.710**), available S (r= 0.716**), pH (r= 0.544**), effective cation exchange capacity (r= 0.711**), water holding capacity (r= 0.690**) and soil moisture (r= 0.740**) and negative correlation with particle density (r= -0.521**) (Appendix II).

In AEU 9, highest N content was observed in Sreemoolanagaram (752.64 kg ha^{-1}) and lowest value was recorded in Kanjoor (225.79 kg ha^{-1}). Highest mean was recorded as 561.97 kg ha^{-1} in Sreemoolanagaram and lowest mean was recorded as 351.23kg ha^{-1} in Edathala (Table 14). The available N status differed significantly between different panchayats. Organic carbon (r= 0.403*), available Mn (r= 0.296**), available B (r= 0.344**), exchangeable acidity (r= 0.239*) and soil moisture (r= 0.310**) were on significant positive correlation with available N, whereas the particle density was significantly negatively correlated with available N (r= -0.259*) (Appendix II).

4.2.6. Available phosphorus

In the post flood soils of AEU 5, the highest mean value of available P was observed in Varapuzha (260.25 kg ha^{-1}) and lowest mean value was found in Elamkunnapuzha (45.71 kg ha^{-1}) (Table 13). The available P varied from 36.6 kg ha^{-1} in Mulavukad to 481.39 kg ha^{-1} in Varapuzha. Available P was found significantly different among different panchayats. Available N (r= 0.648**), available Ca (r= 0.786**), available Mg (r= 0.593**), available S (r= 0.743**), available Zn

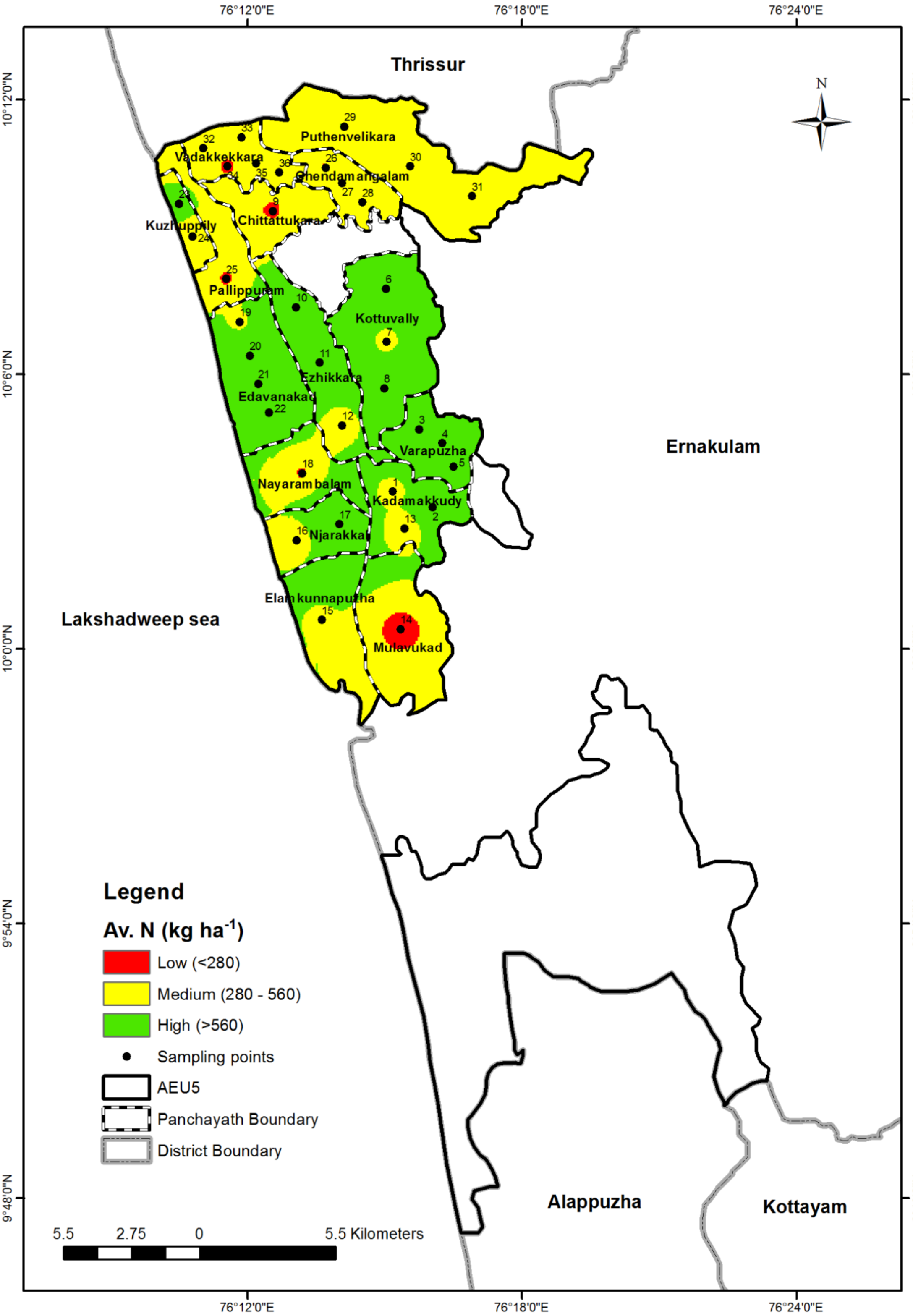

Plate 7. Spatial distribution of available nitrogen in AEU 5

(r= 0.414**), effective cation exchange capacity (r= 0.543**), organic carbon (r= 0.307*), water holding capacity (r= 0.532**) and soil moisture (r= 0.539**) showed positive correlation to available P (Appendix II).

In AEU 9, available P ranged from 8.54 kg ha^{-1} in Chengamanad to 309.09 kg ha^{-1} in Karukutty. The highest mean was found in Alangad (213.45 kg ha^{-1}) and lowest mean in Chengamanad (65.29 kg ha^{-1}) (Table 14). Effective cation exchange capacity (r= -0.242*) and water holding capacity (r= -0.322**) showed negative correlation with P (Appendix II).

4.2.7. Available potassium

The available K in the post flood soils varied from 62.72 kg ha^{-1} in Chendamangalam (uplands) to 3719.34 kg ha^{-1} in Puthenvelikkara under AEU 5 of Ernakulam district. The highest mean value recorded was 3920.92 kg ha^{-1} in Edavanakkad and lowest mean value recorded was 115.36 kg ha^{-1} in Vadakkekkara (uplands) (Table 13). Available K under different panchayats was significantly different. Exchangeable acidity (r= -0.428*) showed negative correlation with available K (Appendix II).

In AEU 9, the highest mean was recorded in Kalady (303.89 kg ha^{-1}) and the lowest mean in Choornikkara (115.13 kg ha^{-1}) (Table 14). The available K in the soil samples varied from 22.4 kg ha^{-1} in Sreemoolanagaram to 956.48 kg ha^{-1} in Edathala. Available Mg (r= 0.267*), available S (r= 0.315**) and water holding capacity (r= 0.253*) showed positive correlation with available K (Appendix II).

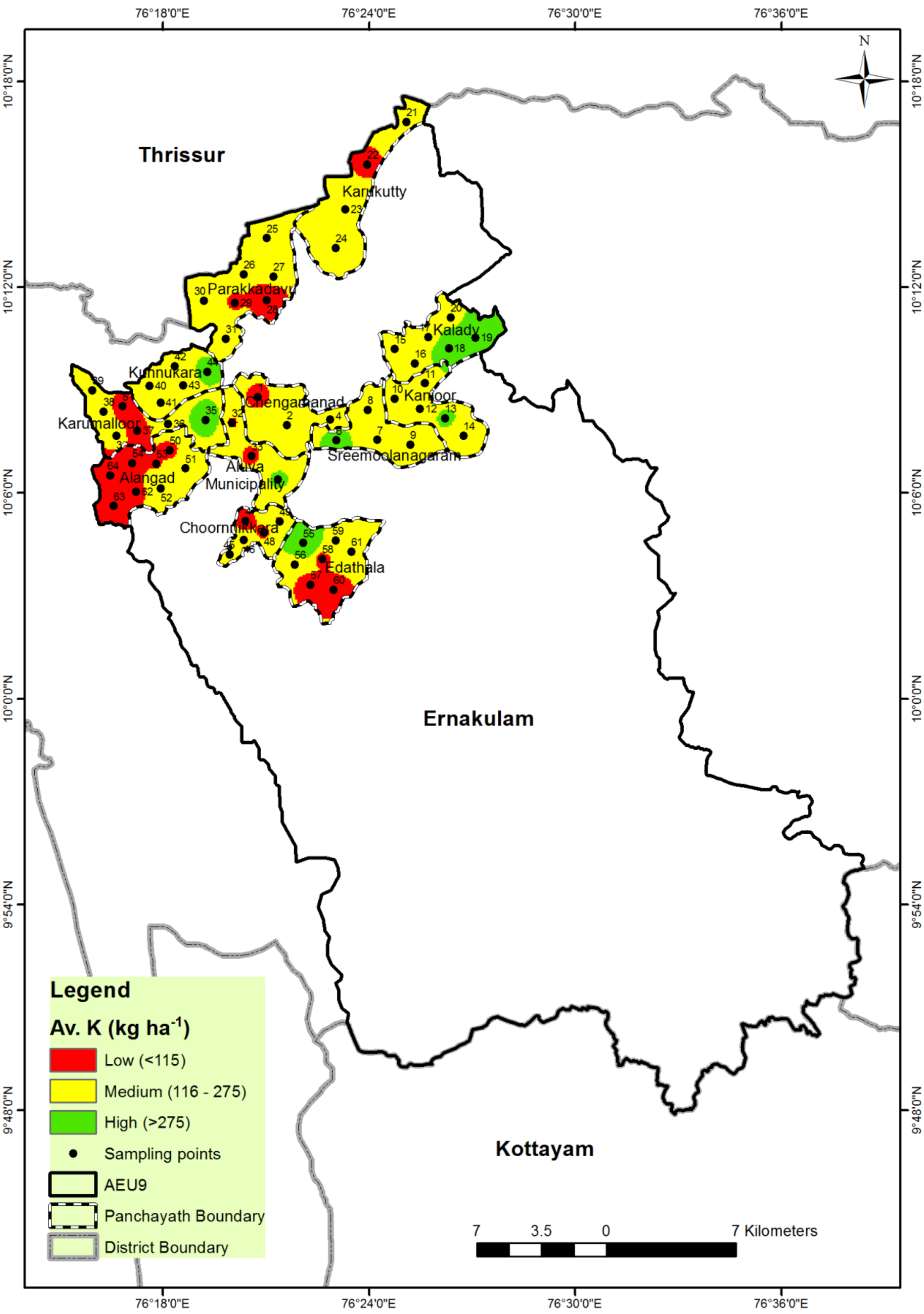

Plate 8. Spatial distribution of available potassium in AEU 9

Table 13. Mean, standard deviation and range of available nitrogen, phosphorus and potassium of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available potassium (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	624.98 ± 477.84	287.09 - 1171.6	134.35^{a} ± 78.27	44.22 - 185.35	1337.81^{cde} ± 629.60	622.81 - 1809.23
Varapuzha	1086.93 ± 475.92	693.92-1616.09	260.25^{abc} ± 203.78	80.04 - 481.39	1701.03^{cde} ± 118.08	1569.09 - 1796.81
Kottuvally	777.02 ± 319.11	476.95-1112.27	117.13^{bc} ± 96.63	57.17 - 228.60	1916.25^{bcd} ± 1509.62	629.24 - 3577.93
Chittatukkara	366.02 ± 421.58	269.63-803.24	142.79^{ab} ± 65.98	60.32 - 195.6	1414.16^{e} ± 524.98	659.54 - 1506.37
Ezhikkara	970.42 ± 615.33	319.59-1542.71	118.03^{bc} ± 81.61	57.30 - 210.81	879.96^{de} ± 865.83	378.53 - 1879.74
Mulavukad	292.44 ± 53.64	172.32-301.87	66.64^{c} ± 23.54	36.28 - 79.89	1302.76^{de} ± 658.49	569.87 - 1784.29
Elamkunnapuzha	546.38 ± 106.54	317.89-754.69	45.71^{c} ± 5.61	41.32 - 59.48	1333.50^{bcd} ± 491.27	897.25 - 2303.69
Njarakkal	965.38 ± 820.46	385.22-1545.53	62.85^{bc} ± 17.57	50.43 - 75.28	2757.77^{abc} ± 1186.09	1919.08 - 3596.46
Nayarambalam	364.88 ± 132.56	251.36-500.87	47.11^{c} ± 9.87	33.85 - 56.21	1908.89^{bcd} ± 367.84	1483.61 - 2549.32
Puthenvelikkara	754.04 ± 346.16	509.26-998.81	83.46^{bc} ± 38.94	55.92 - 111.03	3222.57^{ab} ± 702.53	2725.81 - 3719.34
Edavanakkad	650.05 ± 126.47	560.62-739.49	51.92^{bc} ± 4.34	48.84 - 54.99	3920.92^{a} ± 527.81	3547.7 - 4294.14
Kuzhuppilly	596.40 ± 196.002	457.81-735	49.63^{bc} ± 2.38	47.94 - 51.31	3093.21^{ab} ± 21.77	3077.81 - 3108.61
Pallippuram	457.50 ± 126.48	312.32-623.74	46.93^{c} ± 2.36	42.56 - 50.29	2134.89^{bcd} ± 984.29	1843.57 - 2641.27
Chendamangalam	395.13 ± 97.73	275.96 - 564.48	111.31^{bc} ± 107.72	17.40-274.18	156.24^{bcd} ± 74.11	62.72-245.28
Vadakekkara	323.63 ± 52.02	263.42 - 388.86	143.15^{bc} ± 62.48	41.35-200.45	115.36^{d} ± 23.82	84-150.08

Table 14. Mean, standard deviation and range of available nitrogen, phosphorus and potassium of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	Available nitrogen (kg ha^{-1})		Available phosphorus (kg ha^{-1})		Available potassium (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	410.81^{bcd} ± 85.92	288.51 - 476.67	65.29 ± 81.19	8.54-184.41	130.76 ± 47.02	72.8-175.84
Sreemoolanagaram	561.97^{a} ± 116.46	439.04 - 752.64	202.21 ± 72.20	96.52-281.25	203.61 ± 134.66	22.4-398.72
Kanjoor	366.28^{cd} ± 106.95	225.79 - 526.84	155.46 ± 56.59	87.10-232.36	210.78 ± 71.38	105.28-232.96
Kalady	357.50^{cd} ± 47.43	288.51 - 426.49	119.97 ± 95.04	0.77-264.12	303.89 ± 160.24	109.76-563.36
Karukutty	401.40^{bcd} ± 68.70	313.6 - 476.67	175.27 ± 147.93	38.56-309.09	160.16 ± 65.60	91.84-243.04
Parakkadav	406.78^{bcd} ± 74.16	275.96 - 489.21	130.63 ± 55.94	90.66-207.68	142.56 ± 59.73	61.6-230.72
Aluva	455.76^{b} ± 173.05	326.14 - 652.28	177.57 ± 261.38	37.32-479.14	165.01 ± 118.11	91.84-301.28
Karumaloor	396.39^{bc} ± 77.63	301.05 - 464.12	85.21 ± 61.69	19.24-167.47	238.11 ± 159.56	67.2-489.44
Kunnukara	363.77^{cd} ± 56.09	275.96 - 426.49	164.46 ± 75.89	71.41-256.42	222.88 ± 90.87	132.16-356.16
Choornikkara	368.79^{bcd} ± 38.25	338.68 - 426.49	155.51 ± 55.87	91.02-219.31	115.13 ± 37.19	71.68-165.76
Alangad	398.27^{bcd} ± 86.32	225.79 - 514.30	213.45 ± 199.14	15.19-646.09	117.04 ± 79.95	24.64-246.4
Edathala	351.23^{cd} ± 55.62	275.96 - 426.49	162.69 ± 90.39	55.77-274.26	216.96 ± 331.67	31.36-956.48

4.2.8. Available calcium

The available Ca content in the post flood soils of AEU 5 ranged from 110 mg kg^{-1} in Chendamangalam (uplands) to 3611.94 mg kg^{-1} in Varapuzha. The highest mean was observed in Varapuzha (2451.82 mg kg^{-1}) and lowest value observed was 298.08 mg kg^{-1} in Chendamangalam (uplands) (Table 15). All the panchayats were found to be sufficient in available Ca. Dehydrogenase activity (r= 0.574**), available N (r= 0.676**), available P (r= 0.786**), available Mg (r= 0.857**), available S (r= 0.820**), available Zn (r= 0.488*), available B (r= 0.500*), effective cation exchange capacity (r= 0.838**), porosity (r= 0.405*), soil moisture (r= 0.791**) and water holding capacity (r= 0.851**) showed significant positive correlation whereas bulk density (r= -0.527**) and particle density (r= -0.418*) showed significant negative correlation with available Ca (Appendix II).

In AEU 9 available Ca ranged from 96.5 mg kg^{-1} in Aluva to 1450.5 mg kg^{-1} in Kalady. The highest mean was observed in Kalady (634.16 mg kg^{-1}) and lowest value was recorded in Karukutty (242 mg kg^{-1}) (Table 16). The available Ca content showed significant difference among different panchayats. Out of 12 panchayats, 8 panchayats were sufficient and 4 were found deficient in Ca. Available Mg (r= 0.464**), available Zn (r= 0.421**), pH (r= 0.631**) and effective cation exchange capacity (r= 0.802**) showed significant positive correlation and exchangeable acidity (r= -0.308**) showed significant negative correlation with available Ca (Appendix II).

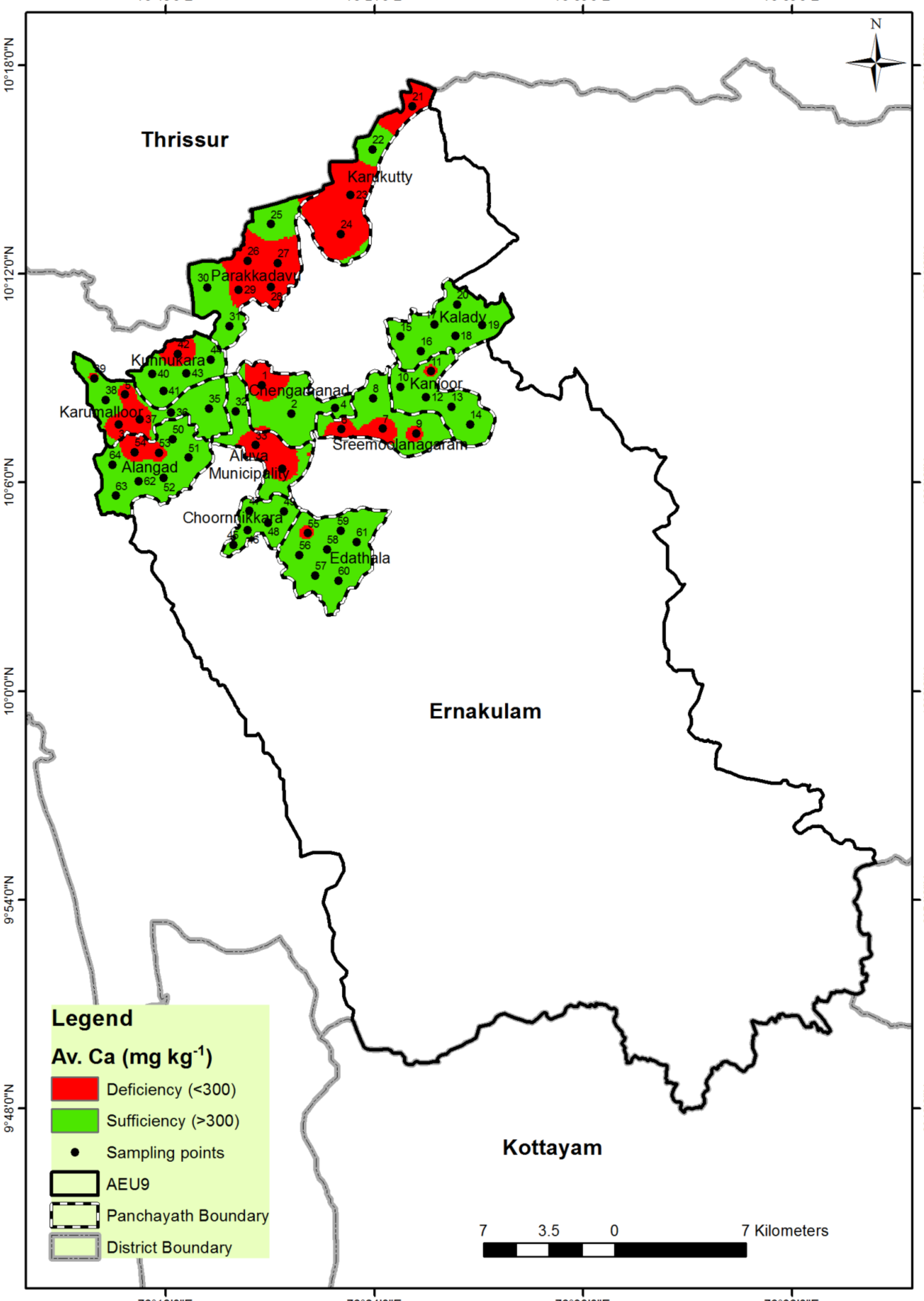

Plate 9. Spatial distribution of available calcium in AEU 5

4.2.9. Available magnesium

Available Mg in the post flood soils of AEU 5 ranged from 26.49 mg kg^{-1} in Chendamangalam (uplands) to 135.34 mg kg^{-1} in Kottuvally. The highest mean value of available Mg was observed in Varapuzha (141.35 mg kg^{-1}) and lowest mean value was found in Chendamangalam (uplands) (39.38 mg kg^{-1}) (Table 15). Out of 15 panchayats, available Mg was sufficient in 15 panchayats and deficient in 3 panchayats. A significant positive correlation with dehydrogenase activity (r= 0.574**), available N (r= 0.710**), available P (r= 0.593**), available Ca (r= 0.857**), available S (r= 0.766**), available Zn (r= 0.482*), available B (r= 0.576**), effective cation exchange capacity(r= 0.969**), water holding capacity (r= 0.905**) and soil moisture (r= 0.960**) and significant negative correlation with bulk density (r= -0.539**) and particle density (r= -0.472**) was observed for available Mg (Appendix II).

In AEU 9, available Mg varied from 29.68 mg kg^{-1} in Kalady to 51.75 mg kg^{-1} in Alangad under AEU 9 of Ernakulam district. The highest mean value was observed at Karumaloor (44.46 mg kg^{-1}) and lowest mean value was observed in Aluva (38.63 mg kg^{-1}) (Table 16). All the panchayats were found deficient in available Mg. It had a significant positive correlation with available K (r= 0.267**), available Ca (r= 0.464**), available Mn (r= 0.302**), pH (r= 0.338**), effective cation exchange capacity (r= 0.497**) and water holding capacity (r= 0.269**) and significant negative correlation with exchangeable acidity (r= -0.393**) (Appendix II).

4.2.10 Available sulphur

The available S in the post flood soils varied from 7.07 mg kg^{-1} in Vadakkekkara (uplands) to 241.73 mg kg^{-1} in Varapuzha under AEU 5. The highest mean value was recorded in Varapuzha (201.45 mg kg^{-1}) and the lowest mean value was recorded in Vadakkekkara (uplands) (10.04 mg kg^{-1}) (Table 15). All the panchayats showed sufficient to toxic levels of S. In correlation analysis, it was found that significant positive correlation with available N (r= 0.716**), available P (r= 0.743**), available Ca (r= 0.820**), available Mg (r= 0.766**), available Zn (r= 0.421*), water holding capacity (r= 0.644**) and soil moisture (r= 0.748**) and significant negative correlation with bulk density (r= -0.441*) (Appendix II).

The available S content of post flood soils varied from 3.73 mg kg^{-1} in Kanjoor to 36.66 mg kg^{-1} in Edathala under AEU 9 of Ernakulam district. The highest mean value was recorded in Edathala (17.18 mg kg^{-1}) and the lowest mean value was recorded in Chengamanad (8.87 mg kg^{-1}) (Table 16). All the panchayats showed sufficient levels of S. The available S under different panchayats was significantly different. Also, the available S were on significant positive correlation with available K (r= 0.315**), available Fe (r= 0.615**), available Mn (r= 0.363**), exchangeable acidity (r= 0.370**), organic carbon (r= 0.316**), porosity (r= 0.328**) and water holding capacity (r= 0.506**) and on significant negative correlation with bulk density (r= -0.290*) (Appendix II).

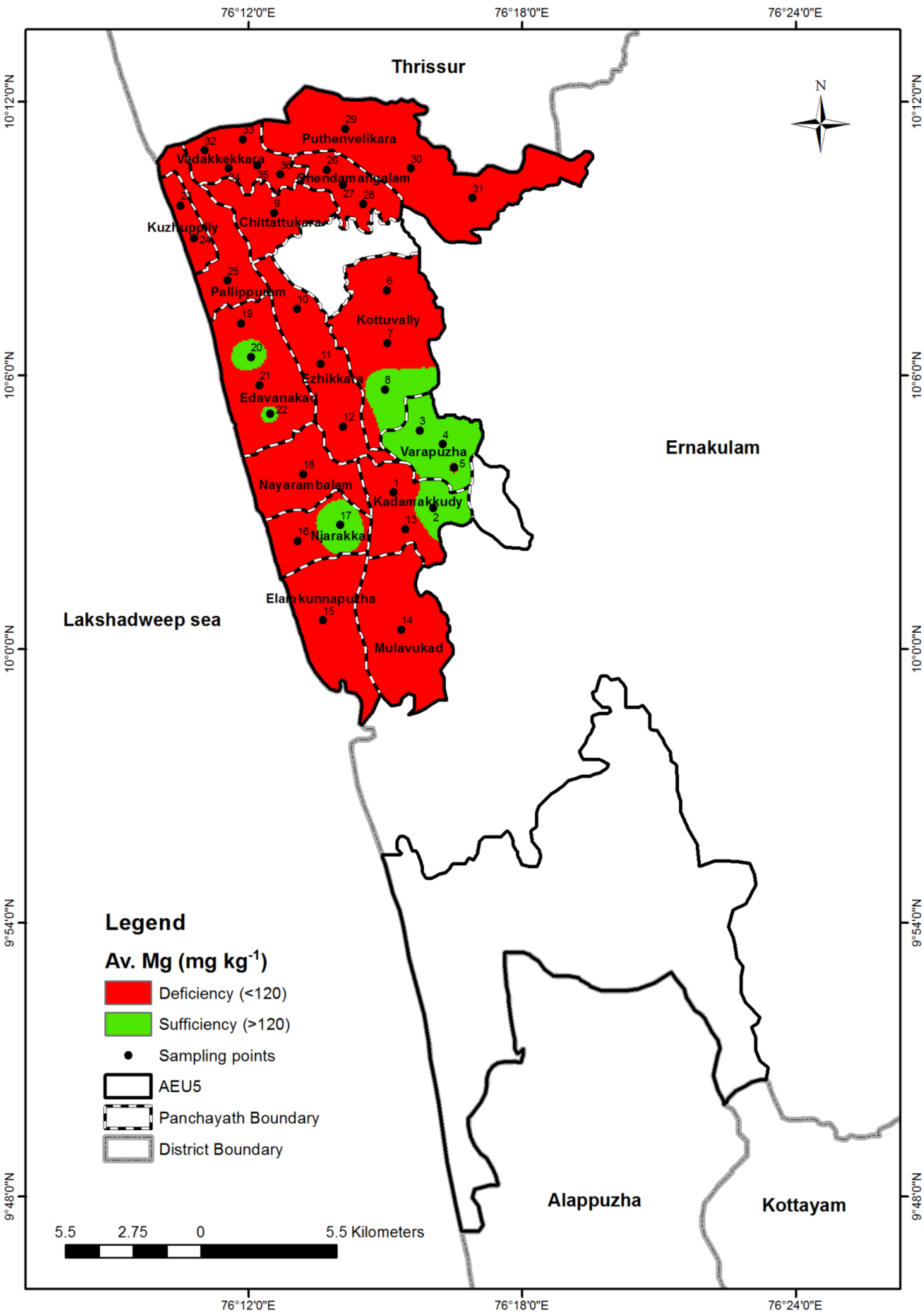

Plate 10. Spatial distribution of available magnesium in AEU 5

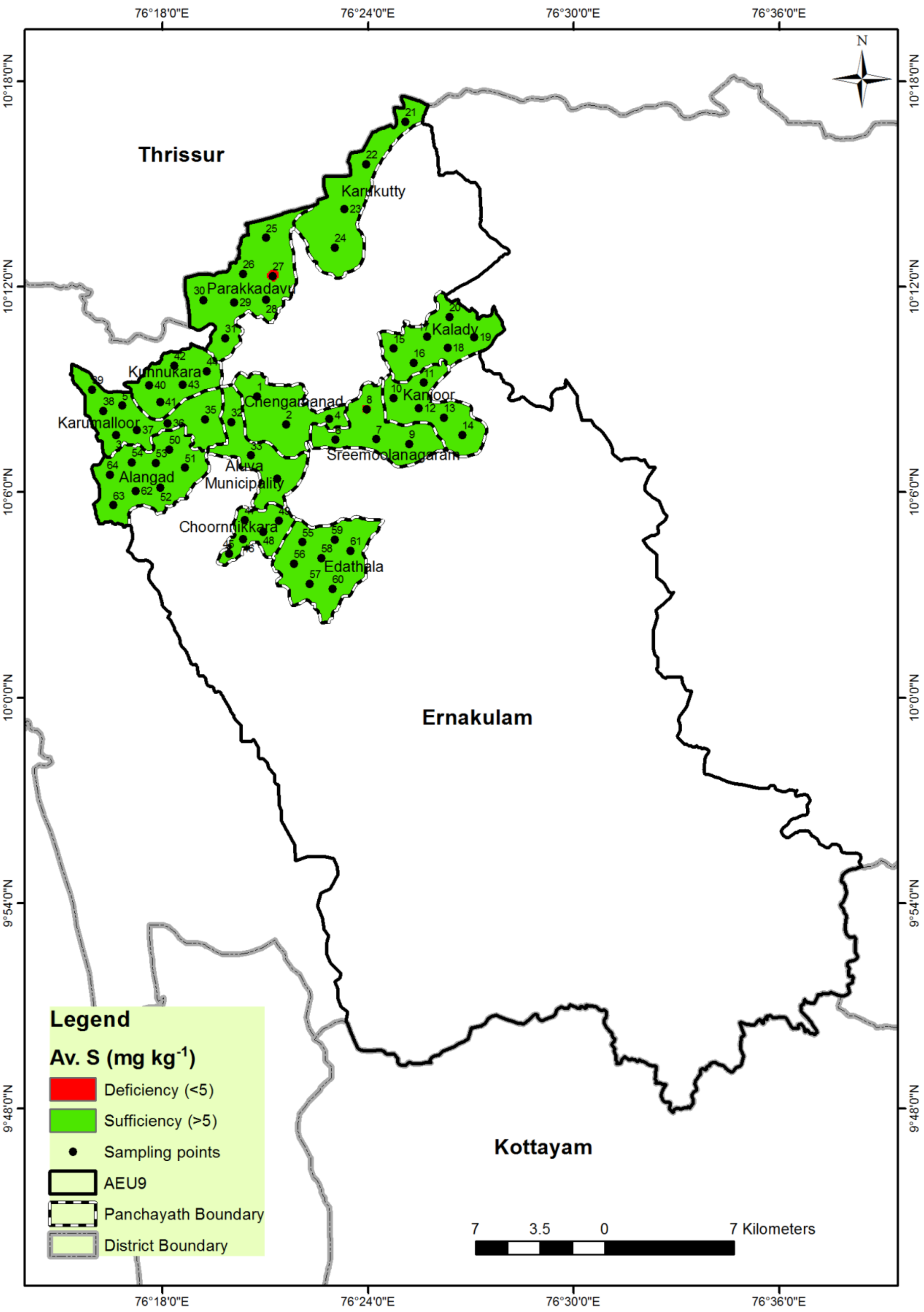

Plate 11. Spatial distribution of available sulphur in AEU 9

Table 15. Mean, standard deviation and range of available calcium, magnesium and sulphur of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available calcium (mg kg^{-1})		Available magnesium (mg kg^{-1})		Available sulphur (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	1553.71 ± 750.33	1064.26 - 2417.58	107.98 ± 43.99	70.27 - 156.31	130.94 ± 54.68	98.35 - 194.07
Varapuzha	2451.82 ± 1004.71	1867.97 - 3611.96	141.35 ± 27.26	119.14 - 171.77	201.45 ± 34.88	180.62 - 241.73
Kottuvally	1088.84 ± 461.50	579.97 - 1480.29	103.31 ± 33.07	69.28 - 135.34	126.73 ± 41.77	81.30 - 163.5
Chittatukkara	744.69 ± 256.21	598.65 - 980.27	94.50 ± 9.32	84.69 - 117.25	111.61 ± 48.96	91.23 - 178.63
Ezhikkara	1213.41 ± 381.79	850.31 - 1611.49	91.91 ± 6.69	86.86 - 99.5	141.76 ± 36.004	105.7 - 177.71
Mulavukad	824.82 ± 300.43	634.01 - 1123.78	82.80 ± 7.51	72.56 - 96.54	104.13 ± 39.64	84.21 - 133.29
Elamkunnapuzha	1024.50 ± 400.28	756.49 - 1326.54	96.64 ± 21.82	71.28 - 112.38	117.24 ± 39.62	94.75 - 141.20
Njarakkal	1500.32 ± 92.74	1434.74 - 1565.9	127.29 ± 23.39	110.74 - 143.83	146.49 ± 31.32	124.34 - 168.64
Nayarambalam	849.17 ± 36.98	698.73 - 987.36	81.82 ± 11.54	69.54 - 99.41	119.55 ± 11.20	95.62 - 129.61
Puthenvelikkara	1610.91 ± 285.28	1402.18 - 1812.64	125.30 ± 8.43	119.33 - 131.26	143.41 ± 28.28	123.4 - 163.41
Edavanakkad	1395.05 ± 141.83	1294.76 - 1495.34	113.71 ± 12.41	104.93 - 122.48	93.79 ± 6.59	89.12 - 98.45
Kuzhuppilly	962.90 ± 6.89	958.02 - 967.77	102.98 ± 4.34	99.9 - 106.05	91.007 ± 26.56	72.22 - 109.79
Pallippuram	902.49 ± 19.87	729.34 - 1112.78	82.25 ± 17.54	79.86 - 110.29	107.48 ± 21.39	98.52 - 132.49
Chendamangalam	398.08 ± 126.15	110 - 473.5	39.38 ± 7.17	26.49 - 44.83	28.93 ± 17.71	10.42 - 45.30
Vadakekkara	654.7 ± 346.87	371.5 - 711	43.94 ± 3.66	41.1 - 50.35	10.04 ± 4.21	7.07 - 17.17

Table 16. Mean, standard deviation and range of available calcium, magnesium and sulphur of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available calcium (mg kg^{-1})		Available magnesium (mg kg^{-1})		Available sulphur (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	282.75^{e} ± 101.80	228 - 392.5	42.31 ± 3.02	39.15 - 46.37	8.87^{c} ± 2.07	3.86 - 10.25
Sreemoolanagaram	266^{e} ± 65.07	194.5 - 371.5	40.37 ± 2.57	38.22 - 44.85	10.18^{c} ± 1.94	8.56 - 13.19
Kanjoor	579.8^{abc} ± 346.98	209.5 - 1146	44.36 ± 3.79	37.88 - 47.38	7.34^{c} ± 0.99	3.73 - 8.21
Kalady	634.16^{ab} ± 416.94	296 - 1450.5	44.12 ± 2.01	41.30 - 46.82	11.34^{c} ± 3.19	7.65 - 12.53
Karukutty	242^{e} ±76.93	142.5 - 330	40.23 ± 3.48	35.73 - 44.2	9.40^{c} ± 1.55	7.53 - 10.79
Parakkadav	297.5^{e} ± 118.97	167 - 504.5	40.78 ± 5.89	167 - 504.5	13.01^{c} ± 4.09	8.87 - 18.01
Aluva	354^{cde} ± 319.82	96.5 - 253.5	38.63 ± 7.95	29.68 - 44.88	12.08^{c} ± 1.31	10.79 - 13.41
Karumaloor	367.6^{e} ± 134.45	207 - 567	44.46 ± 2.40	42.17 - 47.08	13.92^{a} ± 5.41	8.30 - 21.37
Kunnukara	324.2^{de} ± 87.31	200 - 444.5	44.42 ± 3.19	38.81 - 46.31	13.24^{c} ± 2.97	9.86 - 17.82
Choornikkara	425.6^{bcde} ± 96.006	299 - 441.5	43.88 ± 2.35	40.15 - 45.74	10.33^{c} ± 2.11	8.15 - 13.35
Alangad	446.31^{abc} ± 228.30	186 - 911.5	42.19 ± 5.87	32.13 - 51.75	17.02^{b} ± 7.14	9.26 - 28.13
Edathala	425.78^{abcd} ± 162.44	238 - 682	41.81 ± 2.98	36.97 - 45.56	17.18^{c} ± 9.82	8.98 - 36.66

4.2.11. Available iron

The available Fe in the post flood soils varied from 135.8 mg kg^{-1} in Chendamangalam (uplands) to 1966.54 mg kg^{-1} in Kadamakkudy under AEU 5. The highest mean observed was 1452.9 mg kg^{-1} in Puthenvelikkara and the lowest mean observed was 150.64 mg kg^{-1} in Vadakkekara (uplands) (Table 17). All the panchayats showed toxic levels of available Fe. There was significant difference in available Fe among different panchayats. Correlation analysis showed significant positive correlation with dehydrogenase activity (r= 0.457*) and pH (0.545**) (Appendix II).

In the post flood soils under AEU 9, available Fe varied from 16.77 mg kg^{-1} in Karukutty to 380.9 mg kg^{-1} in Edathala. The highest mean was observed in Kunnukara (204.44 mg kg^{-1}) and the lowest mean was observed in Sreemoolanagaram (42.76 mg kg^{-1}) (Table 18). All the panchayats showed sufficient levels of available Fe. There was significant difference in available Fe among different panchayats. Also, available Fe showed significant positive correlation with available S (r= 0.516**), available Mn (r=0.281*), organic carbon (r= 0.304**), porosity (r= 0.334**) and water holding capacity (r= 0.233*) and significant negative correlation with bulk density (r= -0.277*) (Appendix II).

4.2.12. Available manganese

The available Mn values of the post flood soils ranged from 8.91 mg kg^{-1} in Mulavukad to 94.5 mg kg^{-1} in Kadamakkudy under AEU 5. The highest mean value was recorded in Kadamakkudy (60.38 mg kg^{-1}) and the lowest mean value was recorded in Edavanakkad (10.29 mg kg^{-1}) (Table 17). All the panchayats showed sufficient levels of available Mn. Correlation analysis showed that, available Mn had significant positive correlation with available Zn (r= 0.752**) and dehydrogenase activity (r= 0.457*) (Appendix II).

In AEU 9, the highest mean value for available Mn recorded was 72.3 mg kg^{-1} in Kunnukara and the lowest mean recorded was 11.86 mg kg^{-1} in Chengamanad (Table 18). It ranged from 0.06 mg kg^{-1} in Alangad to 138.2 mg kg^{-1} in Aluva and varied significantly among the different panchayats. All the panchayats showed sufficient levels of Mn. Available Mn showed significant positive correlation with available N (r= 0.296**), dehydrogenase activity (r= 0.396*), available Mg (r= 0.302**), available S (r= 0.363**), available Fe (r= 0.516**), effective cation exchange capacity (r= 0.385**), particle density (r= 0.236**), water holding capacity (r= 0.366**) and soil moisture (r= 0.235*) (Appendix II).

4.2.13. Available zinc

The lowest mean value of available Zn was recorded in Kuzhuppilly (2.65 mg kg^{-1}) and highest value was recorded in Kadamakkudy (176.44 mg kg^{-1}) in the post flood soils of AEU 5 (Table 17). It varied from 1.98 mg kg^{-1} in Kuzhuppilly to 250.35 mg kg^{-1} in Kadamakkudy. All the panchayats were found sufficient in available Zn. A significant positive correlation with available P (r=0.414*), dehydrogenase activity (r=0.564**), available Ca (r=0.488**), available Mg (r=0.482**), available S (r=0.421**), available Mn (r=0.752**), available B (r=0.557**), effective cation exchange capacity (r=0.429*) and soil moisture (r=0.437*) was observed (Appendix II).

In the post flood soils of AEU 9, the highest mean value recorded was 21.20 mg kg^{-1} in Edathala and the lowest mean value recorded was 0.97 mg kg^{-1} in Karukutty (Table 18). The available Zn content of soil samples varied from 0.26 mg kg^{-1} in Parakkadav to 64.79 mg kg^{-1} in Choornikkara. All the panchayats were found sufficient in available Zn. It varied significantly among different panchayats. In correlation analysis available Zn showed significant positive correlation with available Ca (r= 0.421**), available Cu (r= 0.589**), pH (r= 0231*) and effective cation exchange capacity (r= 0.361**) and significant negative correlation with soil moisture (r= -0.254*) (Appendix II).

4.2.14. Available copper

Under AEU 5 the highest available Cu content was noticed in Vadakkekkara (uplands) (10.65 mg kg^{-1}). Many of the samples were found to be in below detectable range. The highest mean was observed in Vadakkekkara (uplands) (10.42 mg kg^{-1}) (Table 19). Available Cu was found deficient in 13 panchayats and sufficient in 2 panchayats. Electrical conductivity (r= 0.426*) showed significant positive correlation with available Cu in correlation analysis (Appendix II).

In AEU 9, available Cu varied from 0.06 mg kg^{-1} in Parakkadav to 262.8 mg kg^{-1} in Choornikkara. Some of the soil samples were found had Cu below detectable limit. The highest mean value was recorded in Choornikkara (53.86 mg kg^{-1}) and lowest mean value was recorded in Alangad (0.42 mg kg^{-1}) (Table 20). Available Cu was found sufficient in 8 panchayats and deficient in 4 panchayats. Available Zn (r= 0.599**) showed significant positive correlation with available Cu in correlation analysis (Appendix II).

4.2.15. Available boron

The available B content of the post flood soils ranged from 0.0003mg kg^{-1} in Vadakkekkara (uplands) to 1.256 mg kg^{-1} in Kadamakkudy under AEU 5. The lowest mean value was recorded in Chendamangalam (uplands) (0.019 mg kg^{-1}) and the highest mean value was recorded in Puthenvelikkara (1.09 mg kg^{-1}) (Table 19). Out of 15 panchayats, 8 were sufficient and 7 were deficient in available B. In correlation analysis, available B showed significant positive correlation with dehydrogenase activity (r= 0.612**), available Ca (r= 0.500*), available Mg (r= 0.576**), available Zn (r= 0.557**), effective cation exchange capacity (r= 0.573**), water holding capacity (r= 0.490*) and soil moisture (r= 0.562**) (Appendix II).

Under AEU 9, the lowest mean value was recorded in Parakkadav (0.005 mg kg^{-1}) and the highest mean value was recorded in Sreemoolanagaram (0.124 mg kg^{-1}) (Table 20). The available B of the soil samples ranged from 0.0002 mg kg^{-1} in Parakkadav to 0.187 mg kg^{-1} in Sreemoolanagaram. All the panchayats showed deficiency of B. It showed significant difference among panchayats. Correlation analysis showed that, it had significant positive correlation with available N (r = 0.344**) and significant negative correlation with particle density (r = -0.307**) (Appendix II).

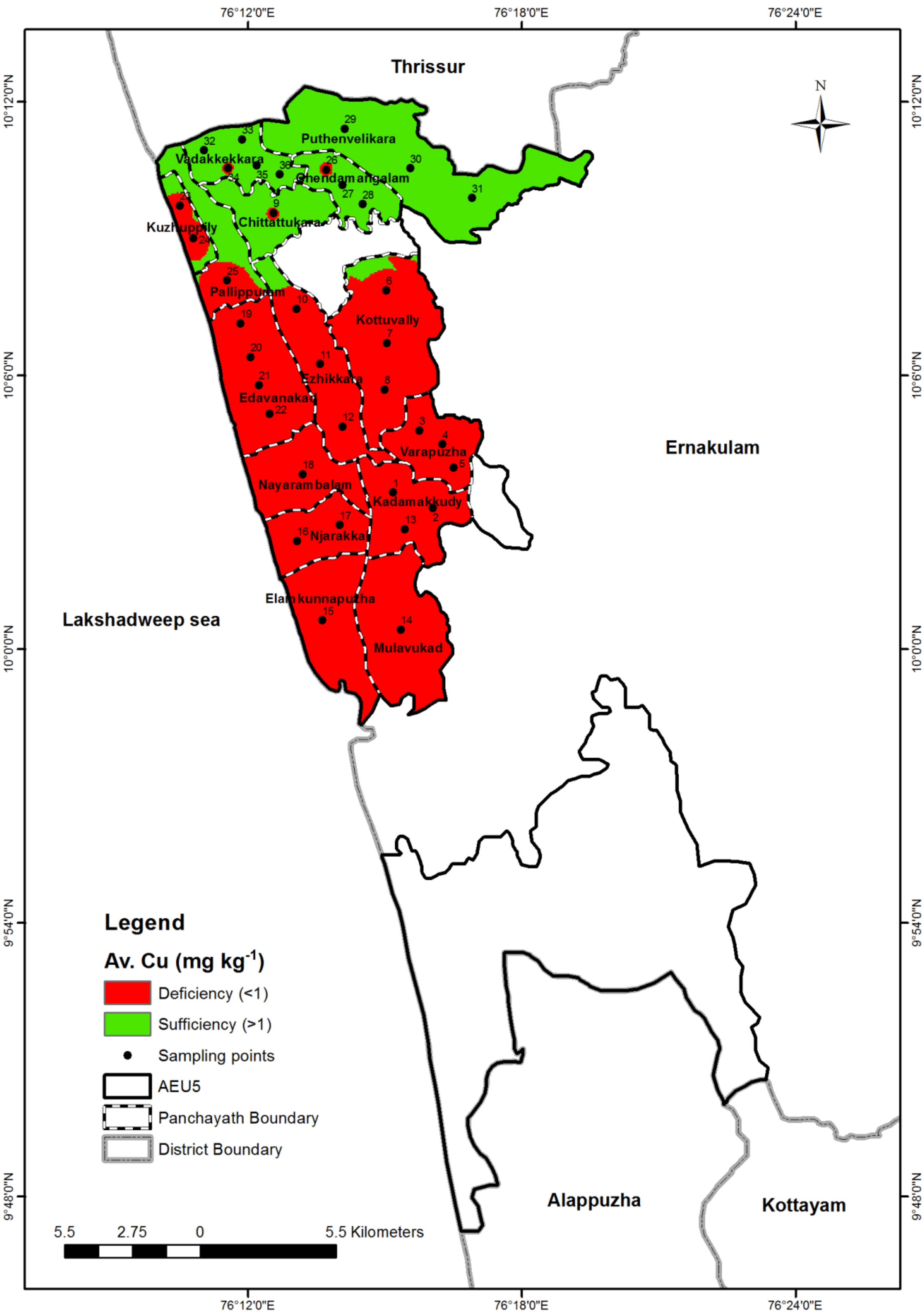

Plate 12. Spatial distribution of available copper in AEU 5

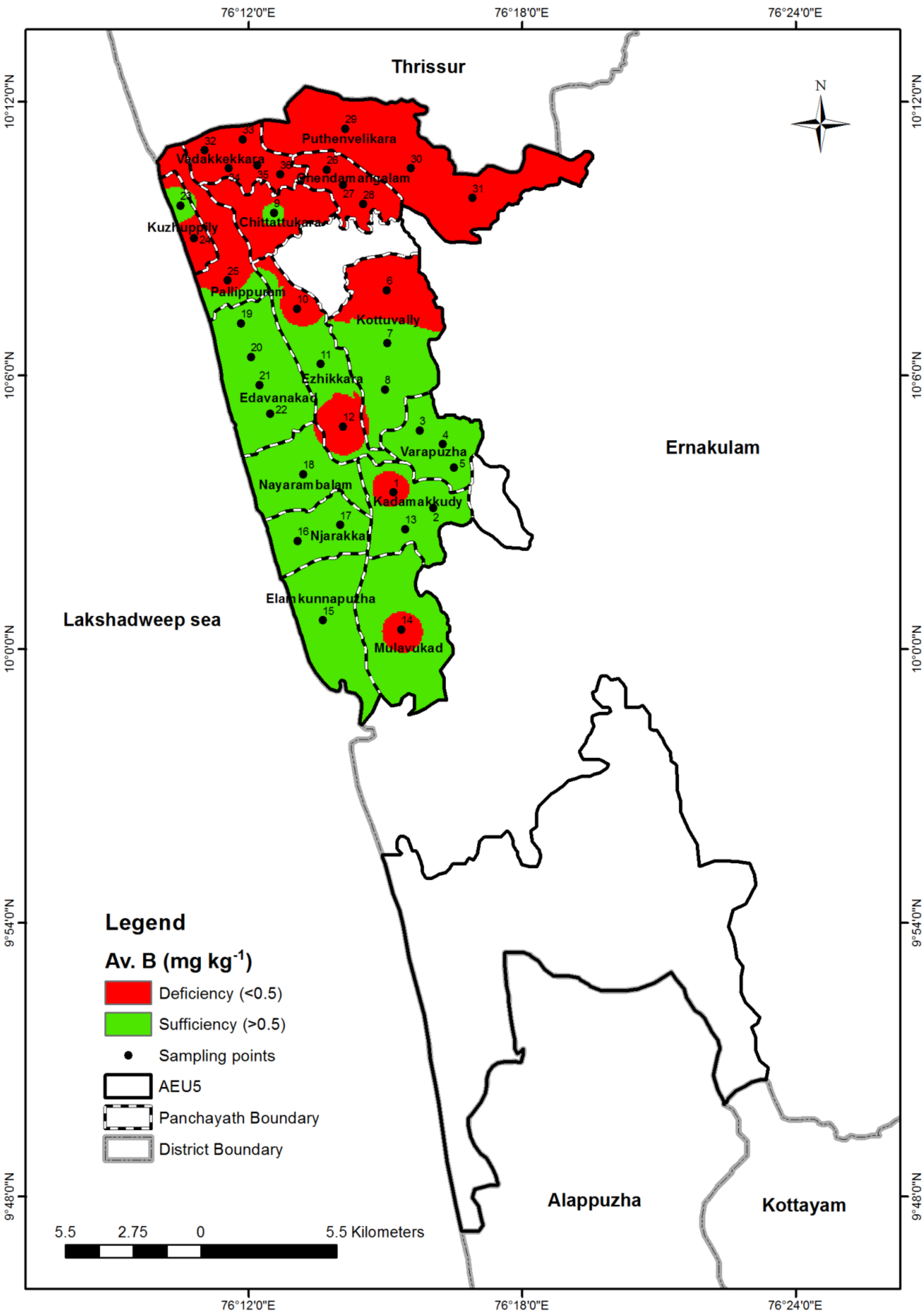

Plate 13. Spatial distribution of available boron in AEU 5

Table 17. Mean, standard deviation and range of available iron, manganese and zinc of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available iron (mg kg^{-1})		Available manganese (mg kg^{-1})		Available zinc (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	1148.24^{abc} ± 710.94	682.30 - 1966.54	60.38 ± 41.58	14.06 - 94.50	176.44 ± 83.71	85.52 - 250.35
Varapuzha	702.73^{c} ± 435.23	367.02 - 1194.47	18.01 ± 8.18	10.02 - 26.38	91.55 ± 55.35	41.76 - 151.16
Kottuvally	793.11^{ab} ± 415.06	440.59 - 1250.57	28.09 ± 5.302	22.7 - 33.30	55.35 ± 26.76	31.04 - 84.03
Chittatukkara	820.55^{bc} ± 578.96	500.36 - 1820.32	24.77 ± 7.69	19.36 - 35.69	70.97 ± 25.41	51.69 - 98.63
Ezhikkara	832.33^{ab} ± 671.75	345.47 - 1598.72	24.24 ± 8.54	15.35 - 32.39	18.37 ± 5.58	11.93 - 21.87
Mulavukad	1225.38^{ab} ± 56.81	1039.27 - 1332.64	18.91 ± 13.65	8.95 - 23.64	16.49 ± 6.54	11.65 - 23.16
Elamkunnapuzha	668.23^{c} ± 39.84	365.94 - 847.91	13.65 ± 6.59	10.79 - 16.25	79.83 ± 15.23	65.98 - 99.65
Njarakkal	945.96^{abc} ± 23.74	929.17 - 962.75	18.36 ± 12.13	9.78 - 26.94	93.004 ± 74.44	40.36 - 145.64
Nayarambalam	1359.27^{a} ± 48.56	1113.98 - 1450.16	15.15 ± 9.54	9.54 - 20.31	20.346 ± 10.87	15.64 - 33.27
Puthenvelikkara	1452.9^{a} ± 87.805	1390.81 - 1514.98	17.23 ± 9.70	10.37 - 24.09	56.47 ± 23.90	39.57 - 73.37
Edavanakkad	1271.92^{ab} ± 40.62	1243.2 - 1300.65	10.29 ± 2.28	8.67 - 11.9	4.58 ± 0.37	4.32 - 4.85
Kuzhuppilly	1303.91^{ab} ± 88.37	1241.42 - 1366.4	11.67 ± 5.51	7.77 - 15.57	2.65 ± 0.95	1.98 - 3.33
Pallippuram	761.29^{abc} ± 25.89	659.84 - 987.23	13.58 ± 11.36	8.65 - 21.56	7.48 ± 2.31	5.36 - 9.54
Chendamangalam	176.93^{bcd} ± 108.43	135.81 - 323.8	60.25 ± 46.55	21.52 - 148.1	3.82 ± 3.97	3.72^{cd} ± 3.97
Vadakekkara	150.64^{bcd} ± 26.42	126 - 191	36.82 ± 9.77	25.6 - 48.68	10.94 ± 8.92	10.94^{bc} ± 8.92

Table 18. Mean, standard deviation and range of available iron, manganese and zinc of soils in different panchayats under AEU 9 of Ernakulam district

Panchayats	Available iron (mg kg^{-1})		Available manganese (mg kg^{-1})		Available zinc (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Mean ± SD
Chengamanad	129.14^{abcde} ± 97.28	43.99 - 220.2	11.86^{e} ± 6.72	3.47 - 19.69	2.008^{cd} ± 1.04	0.74 - 3.25
Sreemoolanagaram	42.76^{f} ± 27.84	18.01- 90.04	17.24^{de} ± 20.53	5.19 - 53.72	1.81^{cd} ± 0.72	0.90 - 2.60
Kanjoor	74.23^{def} ± 62.12	42.17 - 179.2	25.75^{cde} ± 9.85	13.82 - 36.98	8.76^{bcd} ± 4.80	3.01 - 14.6
Kalady	59.82^{ef} ± 50.12	18.32 - 154.9	25.95^{cde} ± 9.20	13.76 - 38.44	7.93^{cd} ± 8.60	1.77 - 24.02
Karukutty	93.52^{cdef} ± 76.14	16.77 - 167	24.57^{cde} ± 18.15	4.89 - 43.52	0.97^{d} ± 0.60	0.37 - 1.70
Parakkadav	113.25^{bcdef} ± 61.28	67.55 - 236.7	45.09^{abcd} ± 36.02	2.23 - 116.7	2.27^{cd} ± 1.55	0.26 - 4.88
Aluva	90.97^{cdef} ± 86.02	19.62 - 186.5	61.54^{ab} ± 68.88	4.83 - 138.2	5.29^{cd} ± 7.08	0.002 - 13.34
Karumaloor	130.52^{a} ± 77.68	42.91 - 247.3	48.512^{ab} ± 10.20	37.13 - 59.27	2.39^{cd} ± 2.21	0.62 - 6.11
Kunnukara	204.44^{a} ± 35.36	169.5 - 250.7	72.32^{a} ± 15.29	54.94 - 90.92	2.34^{cd} ± 0.48	1.81 - 2.84
Choornikkara	192.7^{ab} ± 79.04	101 - 318.4	31.97^{cde} ± 22.09	16.44 - 70.67	18.16^{b} ± 26.31	2.64 - 64.79
Alangad	139.36^{abc} ± 92.13	20.31 - 301.8	31.65^{bcde} ± 26.32	0.069 - 73.32	10.89^{cd} ± 15.52	0.75 - 38.42
Edathala	194.64^{abcd} ± 123.20	83.71 - 380.9	30.69^{cde} ± 23.65	13.49 - 80.14	21.20^{a} ± 17.84	1.07 - 44.5

Table 19. Mean, standard deviation and range of available copper and boron of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available copper (mg kg^{-1})		Available boron (mg kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	0.004 ± 0.003	0.002 - 0.009	0.71 ± 0.52	0.20 - 1.25
Varapuzha	0.001 ± 0.0005	0.001 - 0.002	0.84 ± 0.21	0.65 - 1.08
Kottuvally	0.184 ± 0.315	0.002 - 0.548	0.45 ± 0.26	0.17 - 0.68
Chittatukkara	0.004 ± 0.0013	0.003 - 0.006	0.61 ± 0.32	0.45 - 0.78
Ezhikkara	0.0026 ± 0.002	0.001 - 0.005	0.38 ± 0.12	0.25 - 0.50
Mulavukad	0.002 ± 0.001	0.001 - 0.003	0.42 ± 0.36	0.32 - 0.78
Elamkunnapuzha	0.005 ± 0.002	0.003 - 0.007	0.79 ± 0.31	0.56 - 0.89
Njarakkal	0.005 ± 0.001	0.003 - 0.005	0.73 ± 0.24	0.55 - 0.90
Nayarambalam	0.0025 ± 0.002	0.001 - 0.005	0.62 ± 0.28	0.52 - 0.71
Puthenvelikkara	0.0035 ± 0.0007	0.003 - 0.004	1.09 ± 0.21	0.94 - 1.25
Edavanakkad	0.007 ± 0.0014	0.006 - 0.008	0.64 ± 0.20	0.5 - 0.79
Kuzhuppilly	0.009 ± 0.0007	0.008 - 0.009	0.51 ± 0.29	0.44 - 0.58
Pallippuram	0.005 ± 0.001	0.003 - 0.005	0.39 ± 0.12	0.23 - 0.45
Chendamangalam	2.25 ± 1.53	0.005 - 4.04	0.019 ± 0.018	0.0004 - 0.0306
Vadakekkara	10.42 ± 16.42	0.15 - 10.65	0.031 ± 0.034	0.0003 - 0.089

Table 20. Mean, standard deviation and range of available copper and boron of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Available copper (mg kg^{-1})		Available boron (mg kg^{-1})	
	Mean±SD	Range	Mean ± SD	Range
Chengamanad	0.66 ± 0.83	0.001 - 1.86	0.047^{b} ± 0.030	0.015 - 0.083
Sreemoolanagaram	0.67 ± 0.88	0.001 - 2.05	0.124^{a} ± 0.049	0.05 - 0.18
Kanjoor	20.12 ± 32.42	2.62 - 77.85	0.044^{b} ± 0.059	0.0008 - 0.145
Kalady	6.69 ± 9.21	0.003 - 23.14	0.023^{bc} ± 0.020	0.002 - 0.013
Karukutty	1.84 ± 3.54	0.003 - 7.16	0.029^{bc} ± 0.026	0.001 - 0.057
Parakkadav	1.30 ± 0.77	0.061 - 2.50	0.005^{c} ± 0.011	0.0002 - 0.0324
Aluva	0.958 ± 0.84	0.004 - 1.619	0.042^{b} ± 0.040	0.0006 - 0.0821
Karumaloor	1.91 ± 1.45	0.11 - 4.05	0.022^{bc} ± 0.031	0.0003 - 0.0712
Kunnukara	1.40 ± 0.91	0.42 - 2.77	0.029^{bc} ± 0.015	0.007 - 0.049
Choornikkara	53.86 ± 116.80	0.065 - 262.8	0.034^{bc} ± 0.026	0.002 - 0.050
Alangad	0.42 ± 0.73	0.001 - 2.18	0.038^{b} ± 0.045	0.0007 - 0.142
Edathala	3.56 ± 3.79	0.86 - 10.88	0.018^{bc} ± 0.020	0.002 - 0.058

4.3. BIOLOGICAL ATTRIBUTES

4.3.1. Organic carbon

Highest mean organic carbon content was noticed in Kuzhuppilly (4.63%) and lowest mean was found in Chendamangalam (uplands) (1.07%) in the post flood soils of AEU 5 (Table 21). Organic carbon content in soil varied from 0.22 per cent in Chendamangalam (uplands) to 3.75 per cent in Kuzhuppilly. Organic carbon content varied significantly among different panchayats. Correlation analysis showed that, organic carbon had significant positive correlation with available N (r= 0.568*), porosity (r= 0.244*), water holding capacity (r= 0.271*), dehydrogenase activity (r= 0.314*), microbial biomass content (r= 0.425**), electrical conductivity (r= 0.411*) and available P (r= 0.307*) and negative correlation with bulk density (r= -0.381*) and particle density (r= -0.364*) (Appendix II).

Highest mean of organic carbon was observed in the post flood soils of AEU 9 of Ernakulam district is 1.63 per cent in Choornikkara and lowest mean was observed in Sreemoolanagaram (0.59%) (Table 22). Organic carbon content in soil varied from 0.15 per cent in Kalady to 3.01 per cent in Choornikkara. Organic carbon content varied significantly among different panchayats. Correlation analysis showed significant positive correlation with available N (r= 0.403*), available S (r= 0.304**), porosity (r= 0.124*), dehydrogenase activity (r= 0.523*), microbial biomass carbon (r= 0.444*), water holding capacity (r= 0.147*) and available Mg (r = 0.316**) and negative correlation with bulk density (r = -0.319*) and particle density (r= -0.122*) (Appendix II).

4.3.2. Dehydrogenase activity

Highest dehydrogenase activity was noticed in Kadamakkudy (2090.90 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) and lowest was found in Chendamangalam (uplands) (2.02 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) in the post flood soils of AEU 5. The highest mean value was observed in Puthenvelikkara (1454.72 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) and lowest mean in Chendamangalam (uplands) (11.40 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) (Table 21). Dehydrogenase activity was found to be significantly different among panchayats. Available Ca (r= 0.572**), available Mg (r= 0.574**), available Fe (r= 0.457*), available Mn (r= 0.459*), available Zn (r= 0.564**), available B (r= 0.612**), pH (r= 0.521**), effective cation exchange capacity (r= 0.521**), water holding capacity (r= 0.584**), organic carbon (0.314*) and soil moisture (r= 0.474*) recorded significant positive correlation to dehydrogenase activity (Appendix II).

In AEU 9, the lowest value of dehydrogenase activity recorded was 0.033 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$in Kanjoor and the highest value recorded was 113.29 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$in Kunnukara. The highest mean value was observed in Kunnukara (50.10 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) and lowest mean was observed in Kanjoor (0.46 µg TPF^{-1} g $soil^{-1}$ $24hr^{-1}$) (Table 22). Dehydrogenase activity was found to be significantly different among panchayats. Available Mn (r= 0.396**) organic carbon (r= 0.523*) and particle density (r= 0.301**) showed a significant positive correlation to dehydrogenase activity (Appendix II).

4.3.3. Microbial biomass carbon

The microbial biomass carbon content of the post flood soils in AEU 5 ranged from 10.09 µg g $soil^{-1}$ in Vadakkekkara (uplands) to 870.91 µg g $soil^{-1}$ in Varapuzha. Highest mean value was noticed in Njarakkal (739.19 µg g $soil^{-1}$) and the lowest mean value was noticed in Vadakkekkara (uplands) (35.24 µg g $soil^{-1}$) (Table 21). The microbial biomass carbon showed significant difference among panchayats. It showed a significant positive correlation with organic carbon (r= 0.425**) (Appendix II).

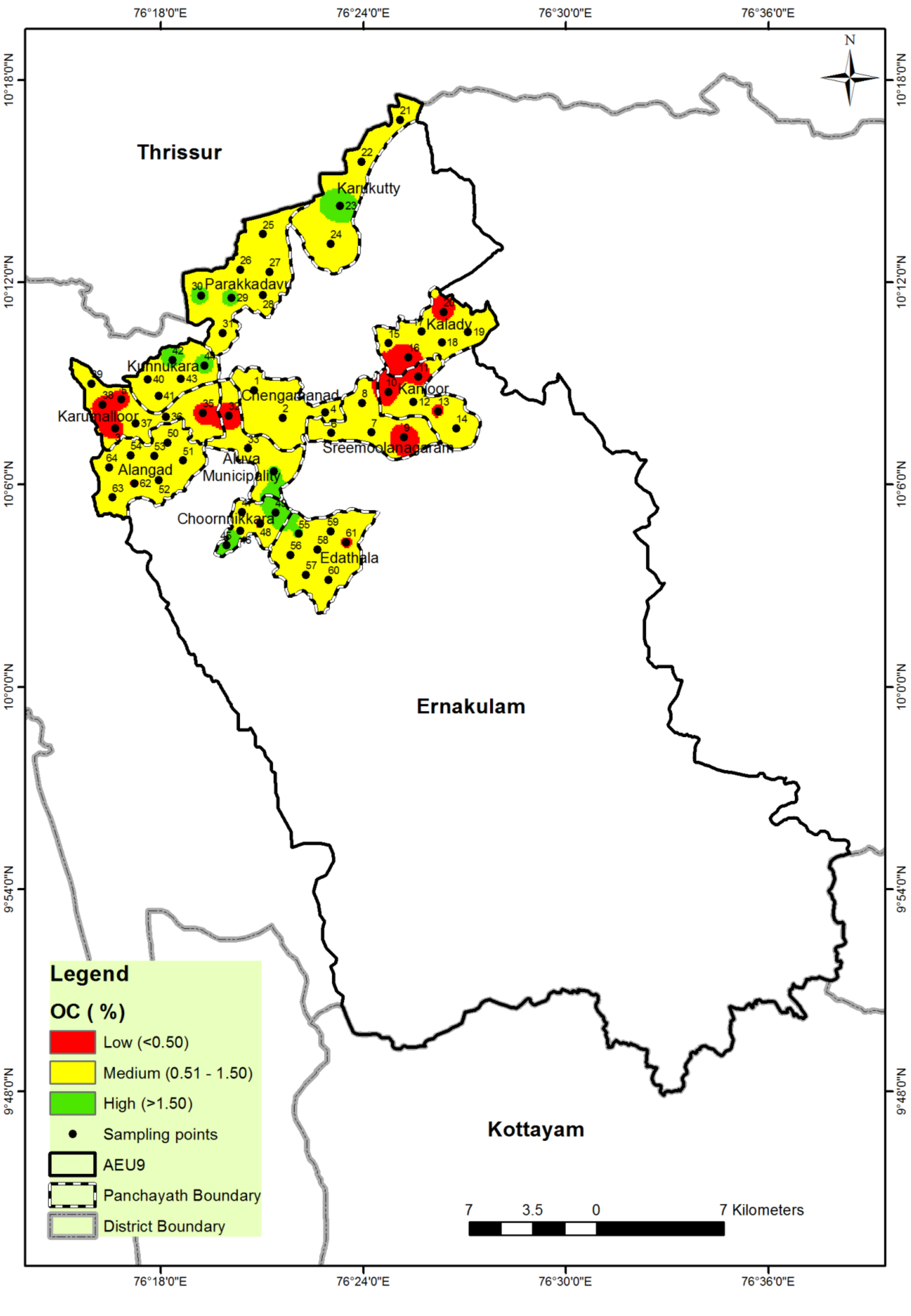

Plate 14. Spatial distribution of organic carbon in AEU 9

In AEU 9, highest mean value was observed in Karumaloor (263.86 µg g $soil^{-1}$) and lowest mean was observed in Kanjoor (44.58 µg g $soil^{-1}$) (Table 22). The microbial biomass carbon content of the soil samples ranged from 391.79 µg g $soil^{-1}$ in Karumaloor to 9.64 µg g $soil^{-1}$ in Parakkadav (Table 20). It showed significant difference among different panchayats. The microbial biomass carbon showed significant positive correlation with organic carbon (r= 0.444*) (Appendix II).

Table 21. Mean, standard deviation and range of organic carbon, dehydrogenase activity and microbial biomass carbon of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Organic carbon (%)		Dehydrogenase activity (µg TPF^{-1} g soil^{-1} 24hr^{-1})		Microbial biomass carbon (µg g soil^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Kadamakkudy	$3.18^{bcde} \pm 2.34$	1.50 - 4.86	$1273.86^{ab} \pm 793.35$	506.52 - 2090.90	$122.60^{c} \pm 81.20$	33.65 - 192.77
Varapuzha	$2.70^{de} \pm 1.11$	2.02 - 3.99	$738.60^{c} \pm 832.87$	66.61 - 1670.42	$629.68^{abc} \pm 224.93$	425.70 - 870.91
Kottuvally	$2.77^{abcd} \pm 1.62$	1.32 - 4.53	$95^{c} \pm 125.11$	40.69 - 237.81	$119.09^{c} \pm 69.007$	43.12 - 177.91
Chittatukkara	$1.81^{cde} \pm 1.54$	1.12 - 3.41	$726.96^{c} \pm 900.32$	52.31 - 1532.98	$288.90^{bc} \pm 56.98$	89.65 - 598.32
Ezhikkara	$3.17^{ab} \pm 1.01$	2.24 - 4.25	$154.93^{c} \pm 231.82$	17.63 - 422.59	$226.99^{c} \pm 109.43$	109.47 - 325.97
Mulavukad	$2.03^{cde} \pm 1.33$	1.23 - 2.96	$290.94^{c} \pm 53.20$	120.98 - 452.31	$245.90^{c} \pm 45.6$	99.86- 350.26
Elamkunnapuzha	$2.99^{abcd} \pm 1.96$	2.03 - 3.6	$341.88^{c} \pm 87.96$	250.69 - 602.98	$700.68^{ab} \pm 59.87$	512.9 - 998.6
Njarakkal	$3.72^{abc} \pm 0.008$	3.71 - 3.72	$594.31^{c} \pm 69.99$	544.82 - 643.81	$739.19^{a} \pm 64.51$	693.57 - 784.81
Nayarambalam	$1.48^{de} \pm 0.96$	1.10 - 2.3	$648.5^{abc} \pm 78.63$	459.78 - 965.32	$346.36^{a} \pm 36.9$	112.36 - 598.78
Puthenvelikkara	$2.72^{bcde} \pm 1.42$	1.7 - 3.73	$1454.72^{a} \pm 58.005$	1413.7 - 1495.74	$140.19^{c} \pm 25.92$	121.86 - 158.52
Edavanakkad	$1.36^{de} \pm 0.07$	1.31 - 1.41	$635.50^{bc} \pm 50.24$	599.97 - 671.03	231.54c ± 175.16	107.68 - 355.4
Kuzhuppilly	$4.63^{a} \pm 0.15$	4.52 - 4.75	$453.40^{bc} \pm 202.87$	309.95 - 596.86	$151.79^{c} \pm 115.26$	70.28 - 233.3
Pallippuram	$1.88^{e} \pm 0.92$	0.88 - 2.1	$328.71^{c} \pm 56.94$	269.02 - 451.08	$358.34^{c} \pm 46.58$	150.69 - 496.17
Chendamangalam	$1.07^{e} \pm 0.95$	0.22 - 2.41	$11.40^{c} \pm 7.16$	2.02 - 20.33	$128.02^{c} \pm 52.69$	62.70 - 199.42
Vadakekkara	$1.16^{de} \pm 0.76$	0.41 - 2.15	$41.29^{c} \pm 20.42$	9.71 - 58.67	$35.24^{d} \pm 28.86$	10.09 - 75.25

Table 22. Mean, standard deviation and range of organic carbon, dehydrogenase activity and microbial biomass carbon of soils in different panchayats under AEU 5 of Ernakulam district

Panchayats	Organic carbon (%)		Dehydrogenase activity (µg TPF^{-1} g soil^{-1} 24hr^{-1})		Microbial biomass carbon (µg g soil^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Chengamanad	0.65^{cde} ± 0.36	0.19 - 1.07	0.82^{de} ± 0.50	0.075 - 1.081	123.40^{bcde} ± 55.12	65.24 - 195.47
Sreemoolanagaram	0.59^{de} ± 0.30	0.25 - 0.88	13.54^{cde} ± 28.45	0.075 - 64.43	102.83^{cdef} ± 56.85	55.04 -183.12
Kanjoor	0.67^{cde} ± 0.50	0.19 - 1.23	0.46^{e} ± 0.53	0.033 - 1.03	44.58^{ef} ± 22.39	27.46 - 82.05
Kalady	0.70^{bcde} ± 0.49	0.15 - 1.33	3.39^{de} ± 6.038	0.075 - 15.62	181.77^{abc} ± 116.95	51.20 - 387.61
Karukutty	1.04^{abcd} ± 0.60	0.53 - 1.84	11.26^{cde} ± 5.03	8.67 - 18.08	224.14^{a} ± 75.33	149.56 - 327.69
Parakkadav	1.20^{abc} ± 0.27	0.88 - 1.55	13.33^{cde} ± 9.39	1.17 - 26.52	68.41^{def} ± 65.32	9.64 - 193.22
Aluva	0.76^{bcde} ± 0.69	0.25 - 1.55	28.241^{abc} ± 44.06	0.53 - 79.05	143.74^{abcd} ± 118.58	63.49 - 279.96
Karumaloor	0.71^{a} ± 0.57	0.22 - 1.55	30.54^{abc} ± 41.90	2.25 - 31.40	263.86^{abc} ± 123.17	61.44 - 391.79
Kunnukara	1.28^{ab} ± 0.45	0.85 - 1.84	50.10^{a} ± 43.52	2.50 - 113.29	158.66^{abc} ± 89.49	67.32- 261.35
Choornikkara	1.63^{a} ± 1.13	0.28 - 3.01	15.43^{cde} ± 7.54	7.70 - 26.22	115.608^{bcdef} ± 45.95	66.91 - 188.54
Alangad	0.98^{abcd} ± 0.38	0.44 - 1.42	20.29^{cde} ± 16.87	1.76 - 45.90	58.98^{def} ± 42.15	18.39 - 156.57
Edathala	0.93^{bcde} ± 0.41	0.60 - 1.58	20.86^{bcd} ± 14.13	9.86 - 50.94	78.81^{def} ± 59.28	9.69 - 187.51

4.4. COMPUTATION OF SOIL QUALITY INDEX

4.4.1. Selection of indicators for minimum data set

Principal component analysis (PCA) was performed for soil attributes to develop minimum data set (MDS). Soil physical, chemical and biological attributes contributed to PCA are bulk density, particle density, porosity, water holding capacity, soil moisture, pH, EC, organic carbon, effective cation exchange capacity, available macro, secondary and micronutrients (N, P, K, Ca. Mg, S, Fe, Mn, Zn, Cu, B), dehydrogenase activity and microbial biomass carbon.

The principle components (PCs) having eigen value greater than 1 was selected. Principle component analysis for sample data of AEU 5 resulted in seven PCs and explained about 36.98 per cent, 14.59 per cent, 8.98 per cent, 7.83 per cent, 6.87 per cent, 5.85 per cent and 5.10 per cent for PC1, PC2, PC3, PC4, PC5 PC6 and PC7 respectively (Table 23). Principle component analysis for sample data of AEU 9 resulted in seven PCs and explained 16.25 per cent, 13.32 per cent, 10.30 per cent, 8.56 per cent, 6.71 per cent, 6.07 per cent and 5.10 per cent for PC1, PC2, PC3, PC4, PC5, PC6 and PC7 respectively (Table 25). Each variable in a particular PC consisted a weight or loading factor which represents the contribution of the variable to the PC. Highly weighted variables were selected from each PC. The weighted variables within 10% of highest loading factor were taken into consideration and when there was more than one variable with higher loading factor was present within a PC, the correlation between the variables were taken. Correlation coefficient of the variables <0.60 was selected and others were eliminated from MDS (Andrews *et al.*, 2002).

In the sample data of the post flood soil samples of AEU 5 of Ernakulam district, from PC1 available Ca, available Mg, effective cation exchange capacity, water holding capacity and soil moisture were with highest loading factor. But only available Mg was selected from PC1. From PC2 available Fe, pH and exchangeable acidity consisted highest loading factor but only available Fe and pH was selected. From PC3, porosity and bulk density had highest loading factor and porosity was selected for MDS. In PC4 available Mn and available Zn were recorded with highest loading factor and available Mn was selected. From PC5 organic carbon was selected for MDS. In PC6 microbial biomass carbon was selected and from PC7 available Cu was selected for MDS. From the total of seven PCs, 8 attributes were taken for MDS (Table 24).

Table 23. Results of principal component analysis for AEU 5

Particulars	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigen values	8.506	3.358	2.067	1.802	1.581	1.346	1.174
% Variance	36.985	14.599	8.989	7.836	6.872	5.853	5.106
Cumulative %	36.985	51.583	60.572	68.409	75.281	81.134	86.240
Eigen vectors							
DHA	0.452	0.628	0.119	0.460	0.046	-0.046	-0.099
N	0.818	-0.410	-0.045	0.102	0.089	0.006	-0.047
P	0.729	-0.167	-0.020	0.284	-0.255	0.027	-0.048
K	0.208	0.606	0.346	-0.536	0.140	-0.026	-0.216
Ca	0.892	0.007	0.179	0.223	-0.058	0.096	0.000
Mg	0.933	0.182	0.195	0.080	0.119	0.073	0.003
S	0.806	-0.250	0.099	0.275	-0.077	0.212	0.131
Fe	-0.146	0.751	-0.122	0.042	0.364	-0.128	0.128
Mn	0.154	0.026	0.231	0.828	0.099	-0.285	-0.002
Zn	0.361	0.139	0.050	0.818	0.225	0.111	-0.063
Cu	-0.048	0.039	0.157	-0.039	-0.078	-0.152	0.943
B	0.416	0.415	0.176	0.294	0.413	0.308	0.094
pH	-0.208	0.833	0.010	0.036	-0.136	-0.139	-0.119
EC	0.070	-0.274	-0.202	0.044	0.545	0.200	0.643
Ex.acidity	-0.054	-0.771	0.135	-0.003	0.267	-0.218	-0.018
OC	0.132	-0.035	0.188	0.157	0.828	-0.031	-0.024
ECEC	0.932	0.147	0.171	-0.012	0.207	0.038	-0.032
BD	-0.404	0.087	-0.860	-0.122	-0.173	0.033	0.022
PD	-0.570	0.201	0.178	-0.130	-0.381	0.475	0.088
Porosity	0.224	-0.027	0.950	0.112	0.015	0.065	0.117
WHC	0.883	0.129	0.297	-0.028	0.167	-0.050	-0.057
Soil moisture	0.908	0.066	0.257	0.021	0.215	0.047	0.015
MBC	0.194	-0.087	0.001	-0.100	0.045	0.913	-0.103

Table 24. Minimum data set (MDS) of AEU 5

PC 1	PC 2	PC3	PC 4	PC 5	PC 6	PC 7
Available magnesium	pH	Porosity	Available manganese	Organic carbon	Microbial biomass carbon	Available copper
	Available iron					

Table 25. Results of principal component analysis for AEU 9

Pariculars	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Eigen values	3.738	3.064	2.369	1.970	1.544	1.398	1.173
% Variance	16.253	13.324	10.301	8.563	6. 712	6.078	5.102
Cumulative %	16.253	29.577	39.877	48.440	55.152	61.230	66.332
Eigen vectors							
DHA	0.128	0.454	-0.279	-0.149	0.290	0.335	-0.017
N	-0.076	0.108	0.079	0.720	0.037	0.175	0.313
P	-0.225	-0.076	-0.241	-0.051	0.078	-0.530	-0.239
K	0.254	0.476	-0.041	0.339	-0.268	-0.305	-0.189
Ca	0.873	-0.073	0.085	-0.047	0.219	0.014	0.013
Mg	0.691	0.169	-0.237	0.245	-0.007	0.115	0.055
S	-0.146	0.722	0.369	0.017	-0.192	0.085	0.061
Fe	-0.129	0.690	0.274	0.036	0.173	-0.076	-0.116
Mn	0.189	0.561	-0.039	0.350	0.253	0.405	-0.148
Zn	0.197	-0.035	0.129	-0.152	0.811	-0.121	0.168
Cu	0.035	-0.024	0.022	0.039	0.714	0.001	-0.077
B	0.002	-0.099	-0.080	0.273	-0.152	-0.015	0.723
pH	0.783	-0.192	0.146	-0.151	-0.204	-0.040	-0.027
EC	0.032	-0.025	-0.143	-0.205	0.338	-0.082	0.589
Ex.acidity	-0.471	0.176	0.428	0.213	-0.089	-0.016	0.013
OC	-0.042	0.596	-0.055	-0.182	-0.106	-0.099	0.008
ECEC	0.775	0.127	0.162	0.248	0.300	0.081	0.015
BD	-0.066	-0.053	-0.912	-0.180	-0.053	0.065	0.057
PD	0.025	0.297	0.128	-0.587	0.205	0.441	-0.209
Porosity	0.074	0.155	0.897	-0.043	0.130	0.105	-0.139
WHC	0.283	0.454	0.326	0.196	-0.343	0.299	0.284
Soil moisture	0.148	-0.094	0.248	0.721	-0.079	0.083	-0.194
MBC	-0.077	-0.173	-0.128	0.105	-0.144	0.742	-0.196

Table 26. Minimum data set (MDS) of AEU 9

PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Available calcium	Available sulphur	Bulk density	Available nitrogen	Available zinc	Microbial biomass carbon	Available boron
	Available iron		Soil moisture			

In the sample data of the post flood soils of AEU 9, from PC1 available Ca and pH consisted highest loading factor, but only available Ca was selected for MDS. From PC2 available S and available Fe consisted highest loading factor, both showed correlation coefficient <0.60 and both were selected. In PC3 bulk density and porosity had highest loading factor, but bulk density was selected for MDS. From PC4 soil moisture and available N was selected for MDS. In PC5 available Zn was selected. In PC6 microbial biomass carbon and from PC7 available B was selected for MDS. From the total of seven PCs, 9 attributes were taken for MDS (Table 26).

4.4.2. Development of scores for minimum dataset indicators

After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods. Three types of scoring curves were used (Andrews *et al.*, 2002).

4.4.2.1. '*More is better'* function

In the sample data of the post flood soils of AEU 5, '*more is better'* function was assigned for microbial biomass carbon, available B, available Cu, organic carbon and available Mg. In '*more is better'* function, highest score was given to the highest value of the soil attribute and the lowest score to the lowest value of particular soil attribute. Non-linear scoring was done here using the equation:

$$S_{NL} = a/1+(X/X_m)^b$$

where S_{NL} is the score of the soil indicator, a is the maximum score reached by the function which is equal to 1, X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation and is set as −2.5 for a '*more is better*' curve. The values of each MDS indicators were arranged in ascending order and the non-linear scoring equation was applied. '*More is better'* function was used for soil organic matter and water stable aggregates because of their role in soil fertility, water partitioning and stability of structure (Tiessen *et al.*, 1994). The scoring curves assigned to the each soil attributes was based on the influence of that soil attribute in soil quality.

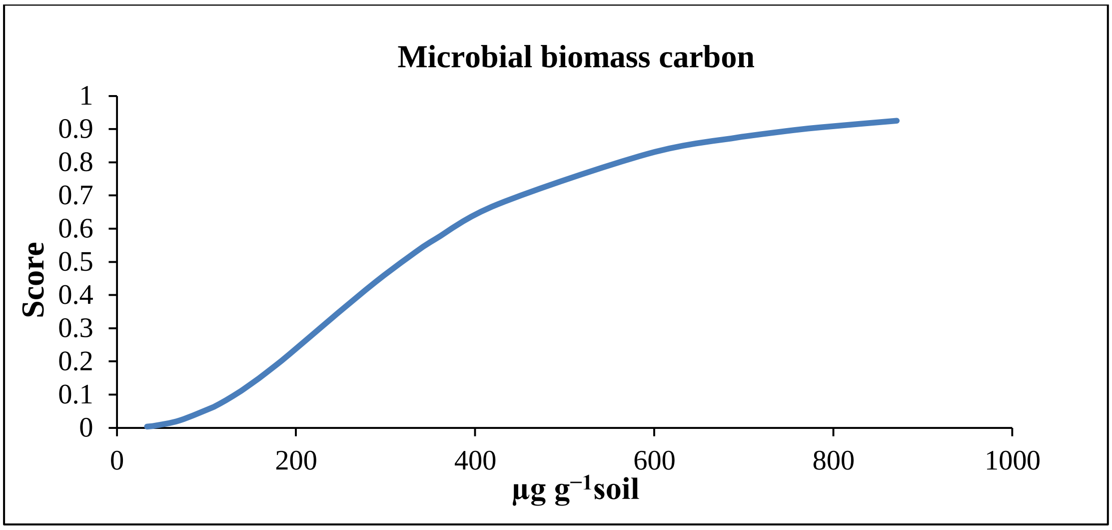

Fig. 2. '*More is better'* score curve for microbial biomass carbon

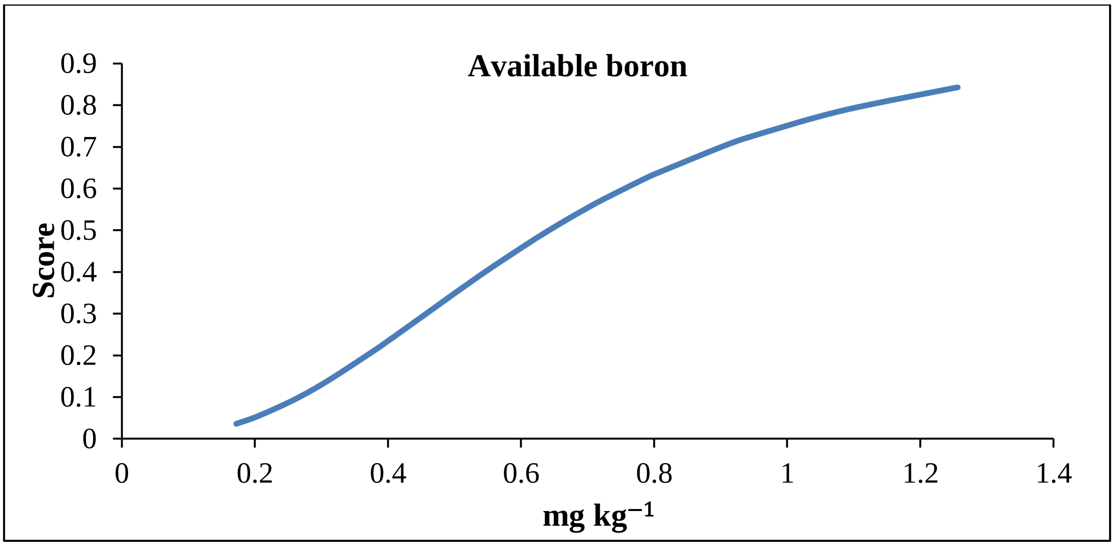

Fig. 3. '*More is better'* score curve for available boron

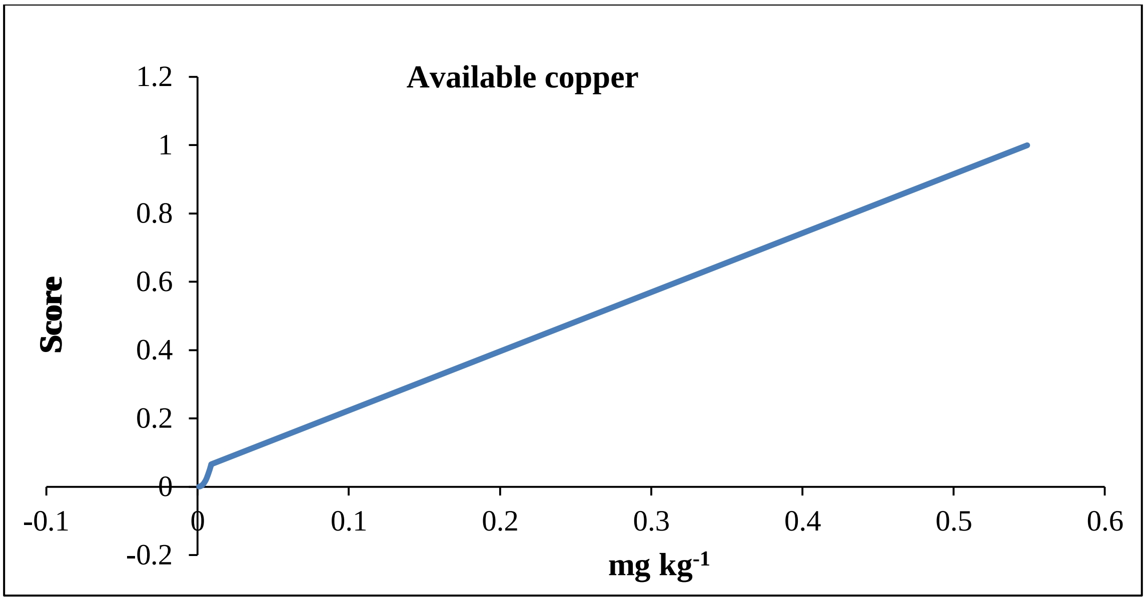

Fig. 4. '*More is better'* score curve for available copper

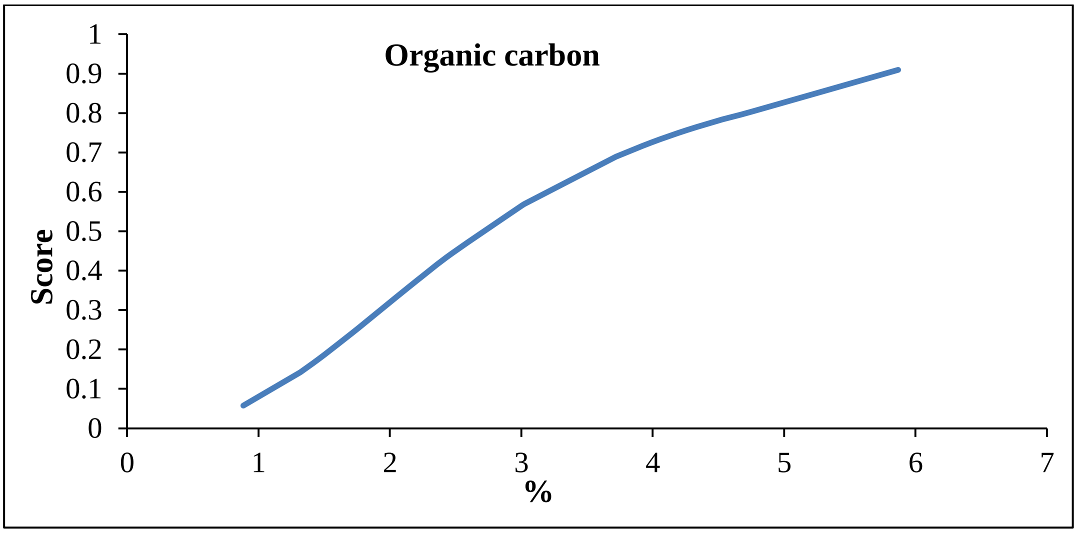

Fig. 5. '*More is better'* score curve for organic carbon

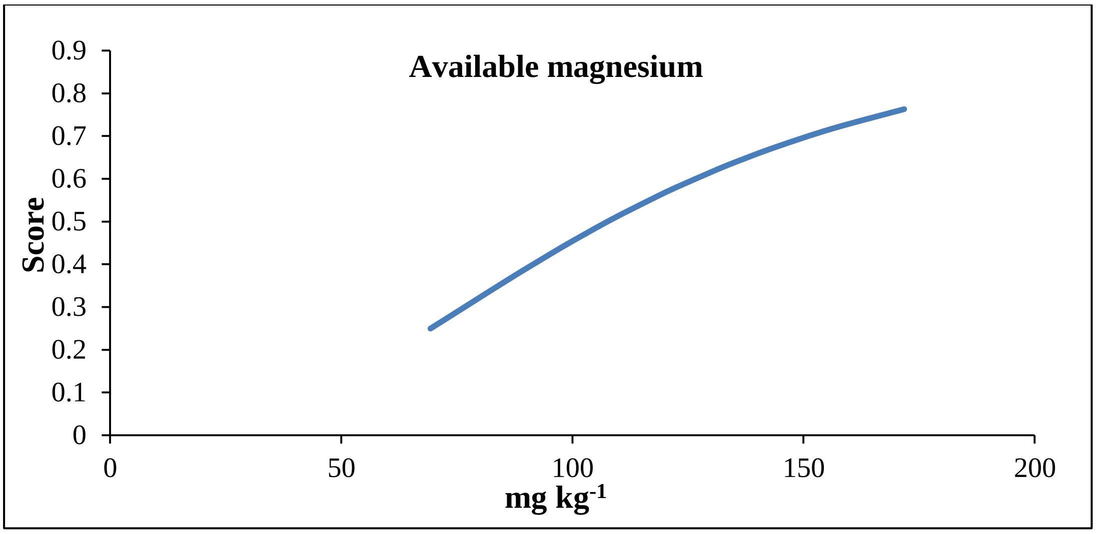

Fig. 6. '*More is better*' score curve for available magnesium

In the sample data of the post flood soils of AEU 9 '*more is better'* function was assigned to microbial biomass carbon, available B, available Ca and available N.

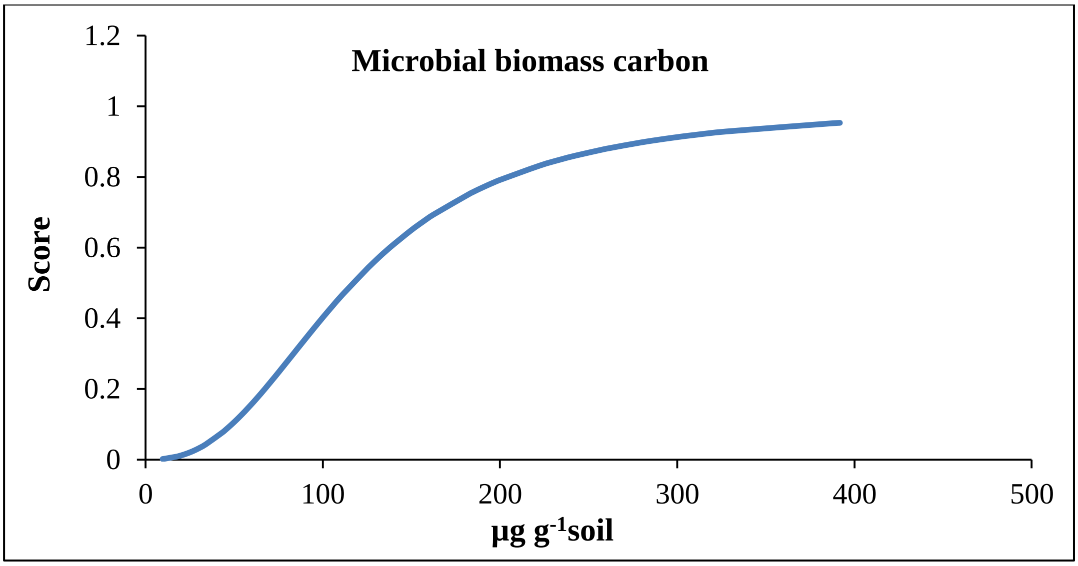

Fig. 7. '*More is better'* score curve for microbial biomass carbon

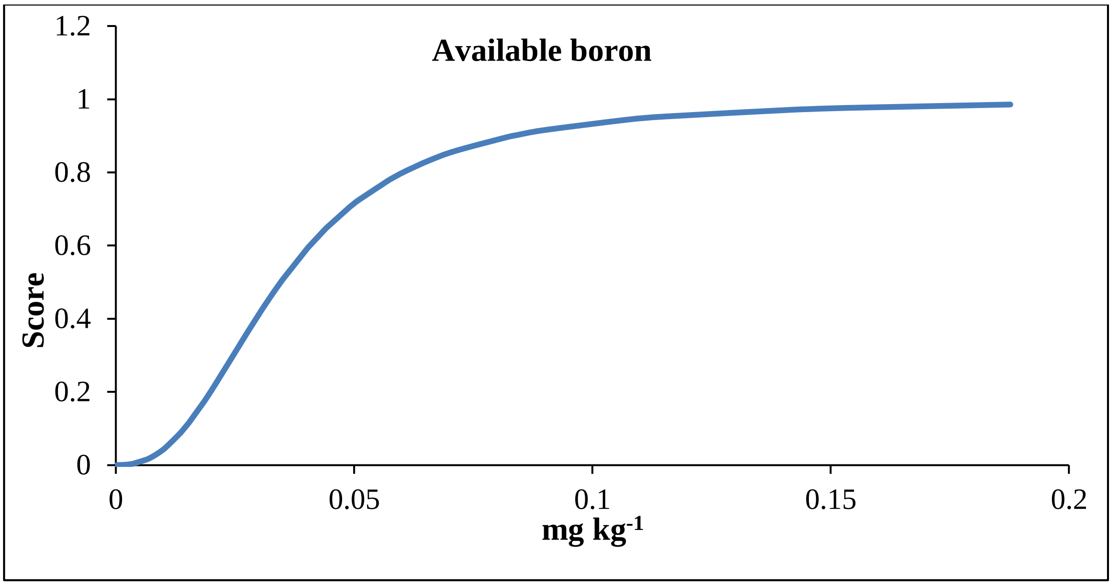

Fig. 8. '*More is better'* score curve for available boron

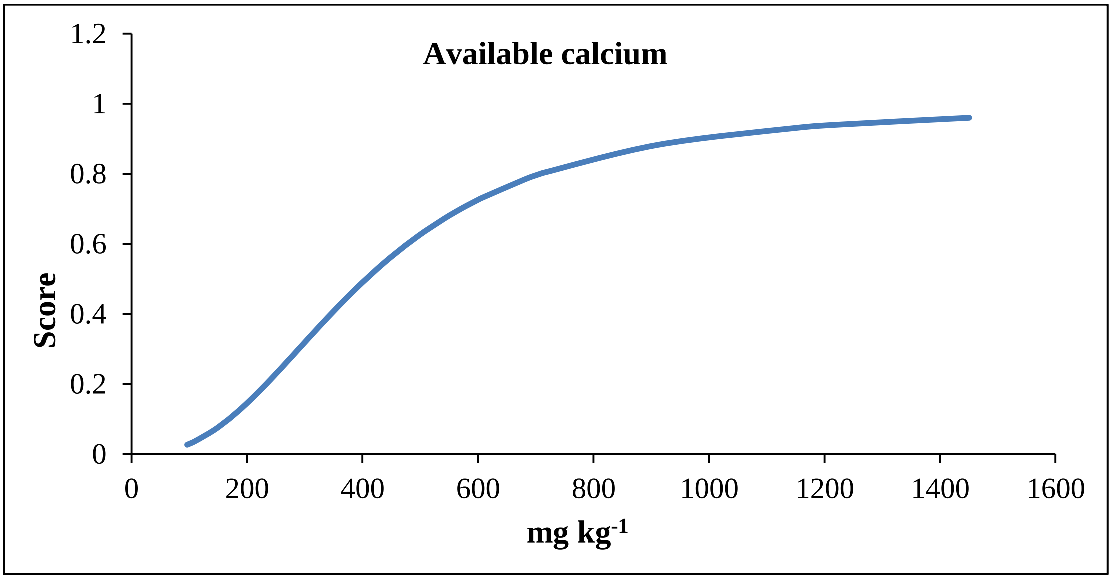

Fig. 9. '*More is better'* score curve for available calcium

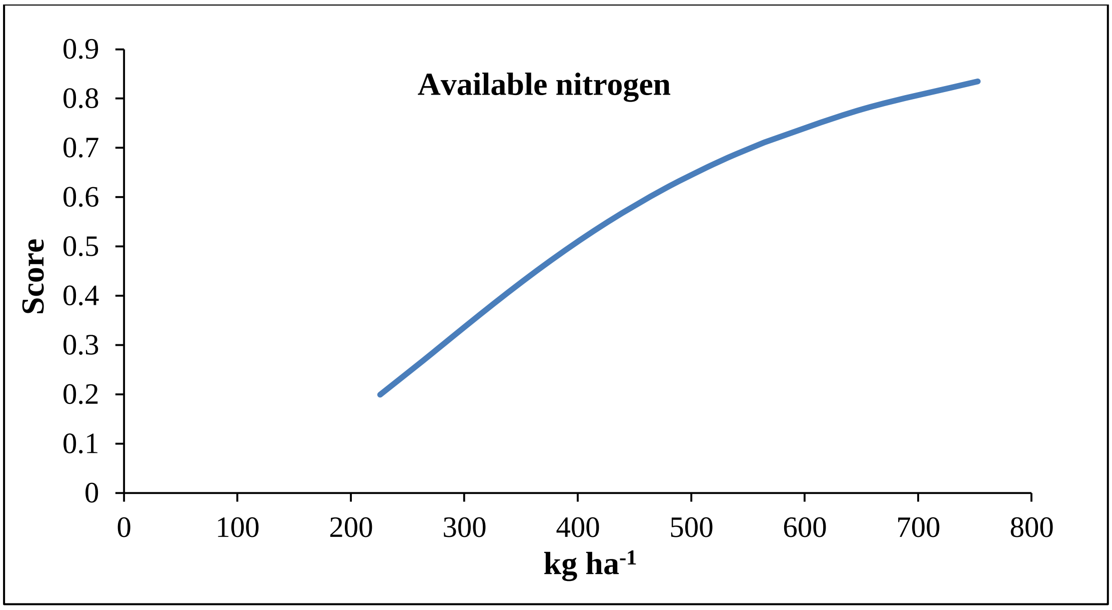

Fig. 10. '*More is better'* score curve for available nitrogen

4.4.2.2. '*Less is better'* function

In the sample data of the post flood soils of AEU 5 '*less is better'* function was assigned for available Fe and available Mn. The observed available Fe level were found to be in toxic range so the '*less is better'* is used for scoring. The observed value for available Mn was also found in toxic range so the '*less is better'* is used for scoring. Scoring was done by non-linear scoring function using the equation:

$$S_{NL} = a/1+(X/X_m)^b$$

where b is the slope of the equation and here value is 2.5 for a '*less is better*' curve. The values of each MDS indicators were arranged in descending order and the non-linear scoring equation was applied.

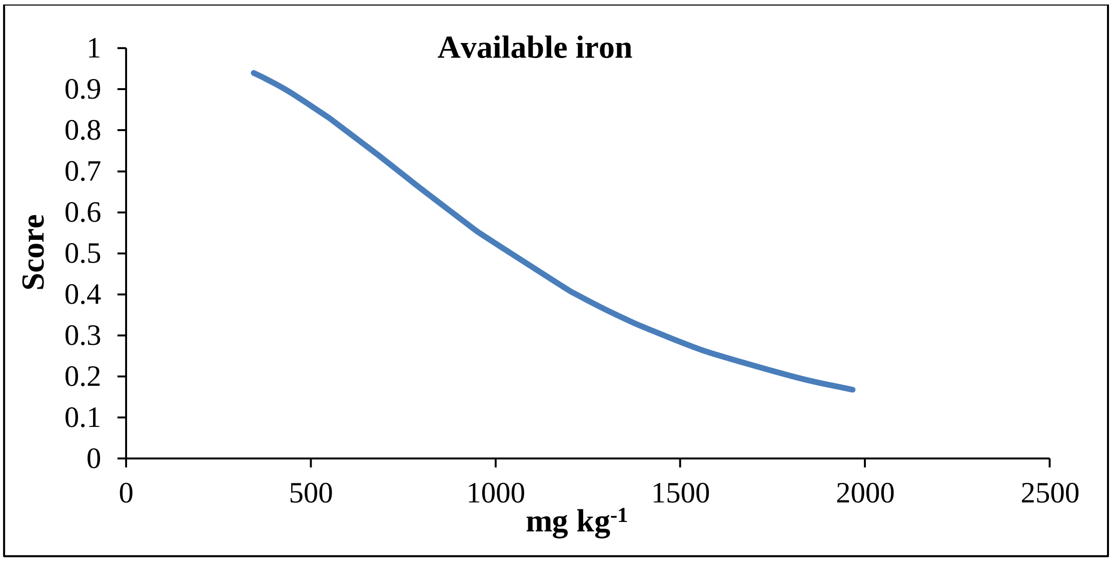

Fig. 11. '*Less is better'* score curve for available iron

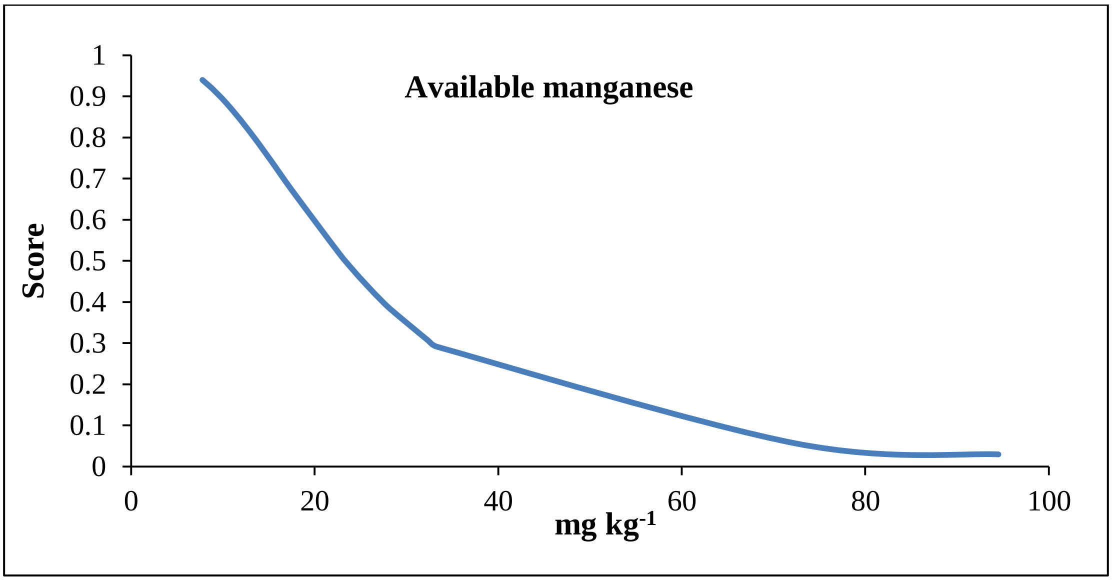

Fig. 12. '*Less is better'* score curve for available manganese

In the sample data of the post flood soils of AEU 9 '*less is better'* function was used in available Fe, bulk density, available Zn and available S. Due to the inhibitory effect of higher bulk density on soil porosity and plant root growth, bulk density is given '*less is better'* function (Soil Survey Staff, 1998). The observed available Fe level were found to be in high range (>100 mg kg^{-1}), available Zn and available S also were in toxic levels so the '*less is better'* is used for scoring.

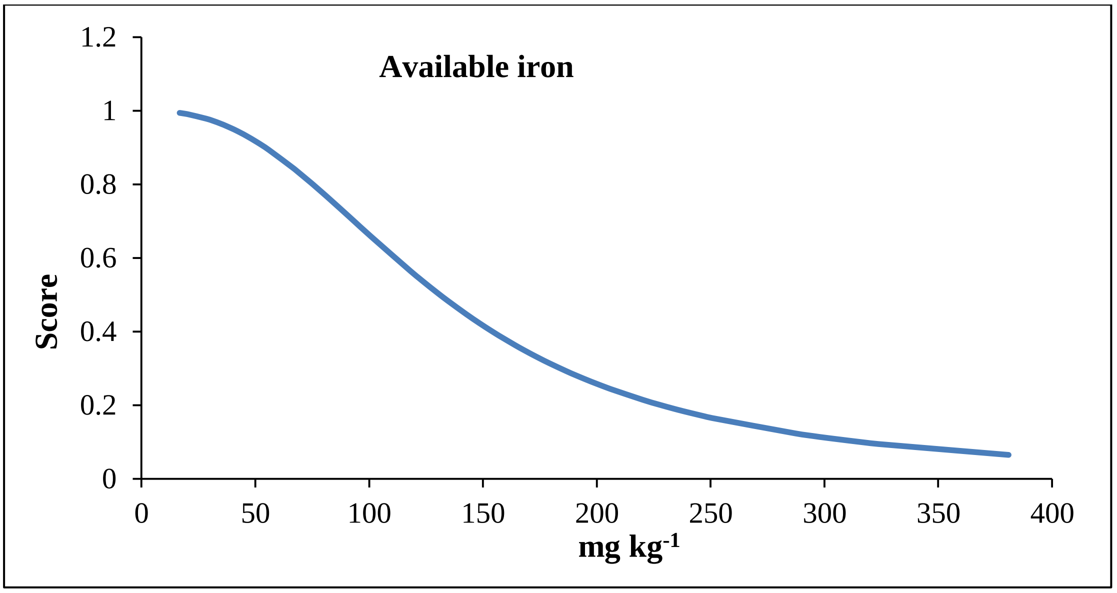

Fig. 13. '*Less is better'* score curve for available iron

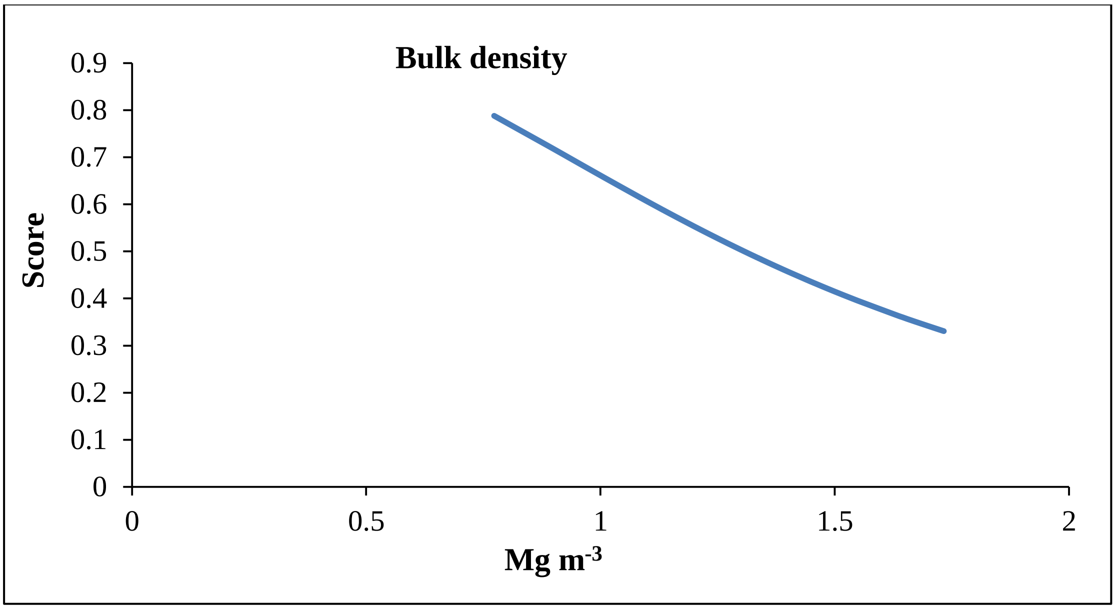

Fig. 14. '*Less is better'* score curve for bulk density

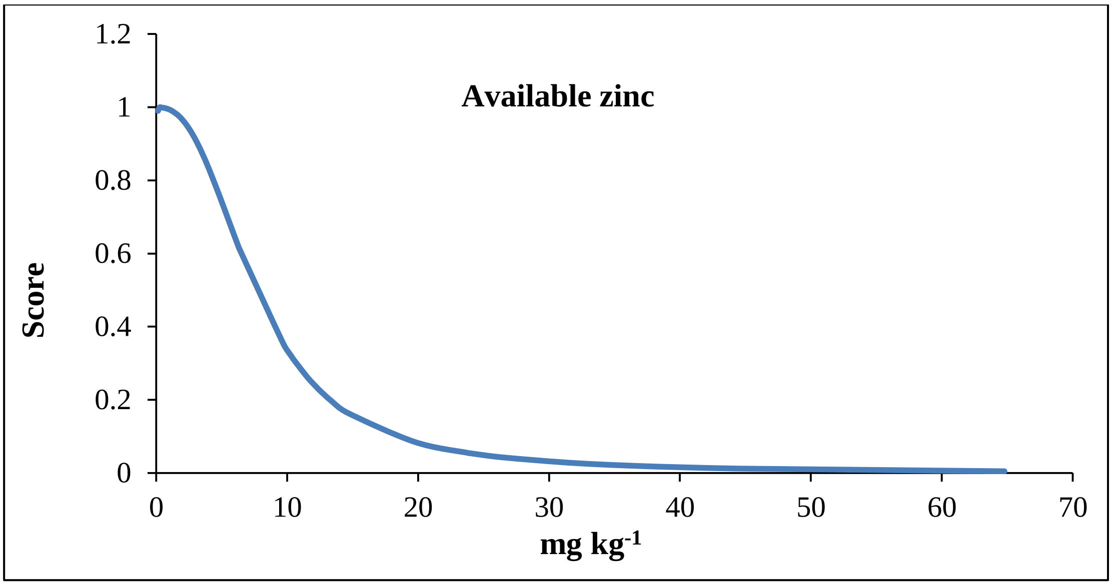

Fig. 15. '*Less is better*' score curve for available zinc

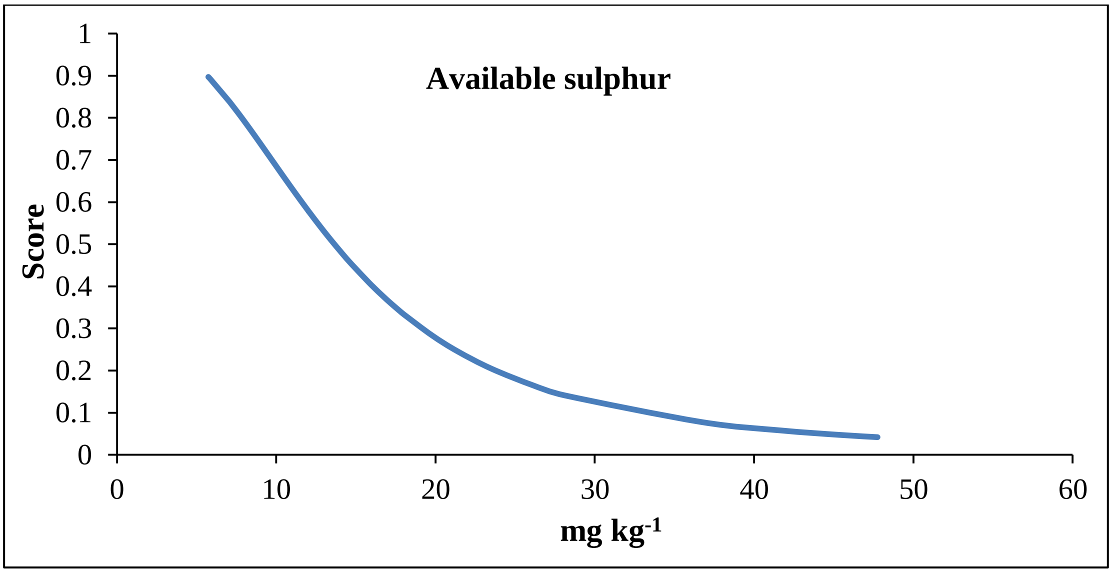

Fig. 16. '*Less is better*' score curve for available sulphur

4.4.2.3. '*Optimum*' curve

In the sample data of the post flood soils of AEU 5, '*Optimum*' curve was used for pH, porosity and in AEU 9 soil moisture was given '*Optimum*' curve. The values of each MDS indicators were arranged in ascending order; optimum value of a particular parameter was selected and given highest score. The values lower than optimum were given *'more is better'* function equation and values greater than optimum was given *'less is better'* function equation.

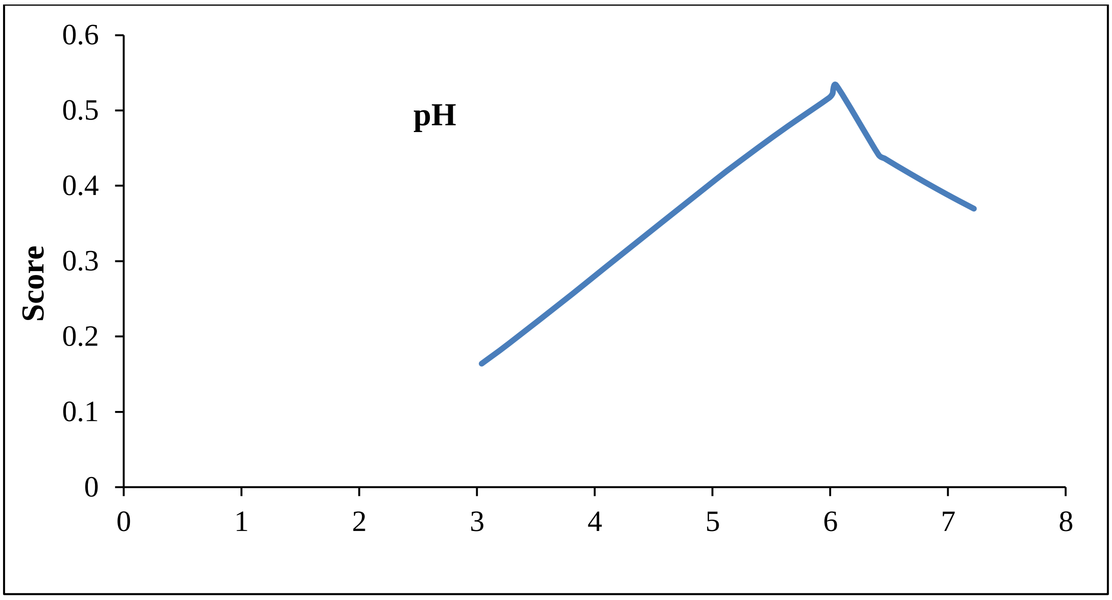

Fig. 17. *Optimum* score curve for pH

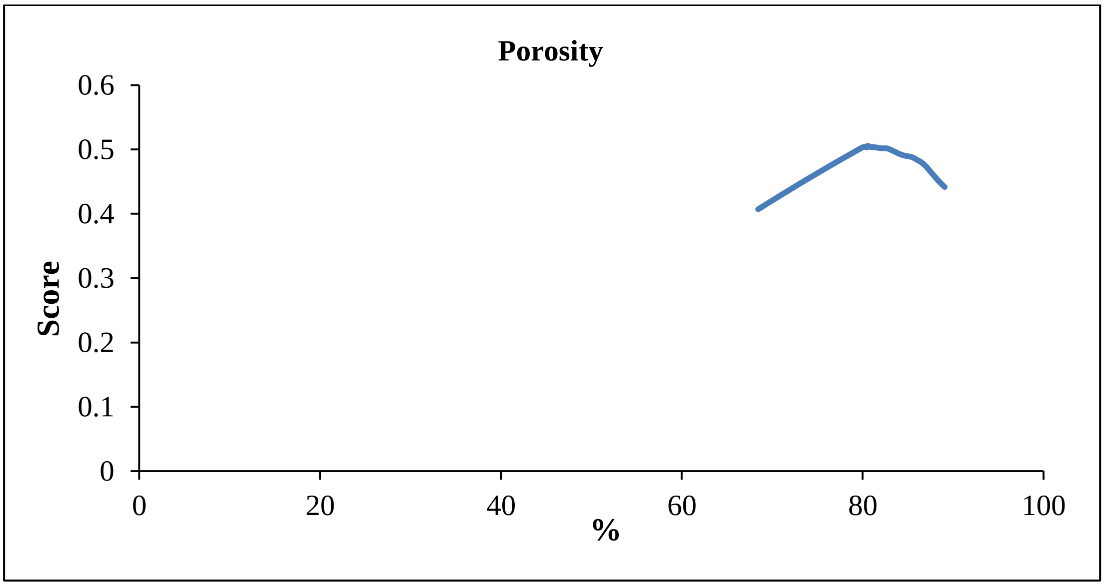

Fig. 18. *Optimum* score curve for porosity

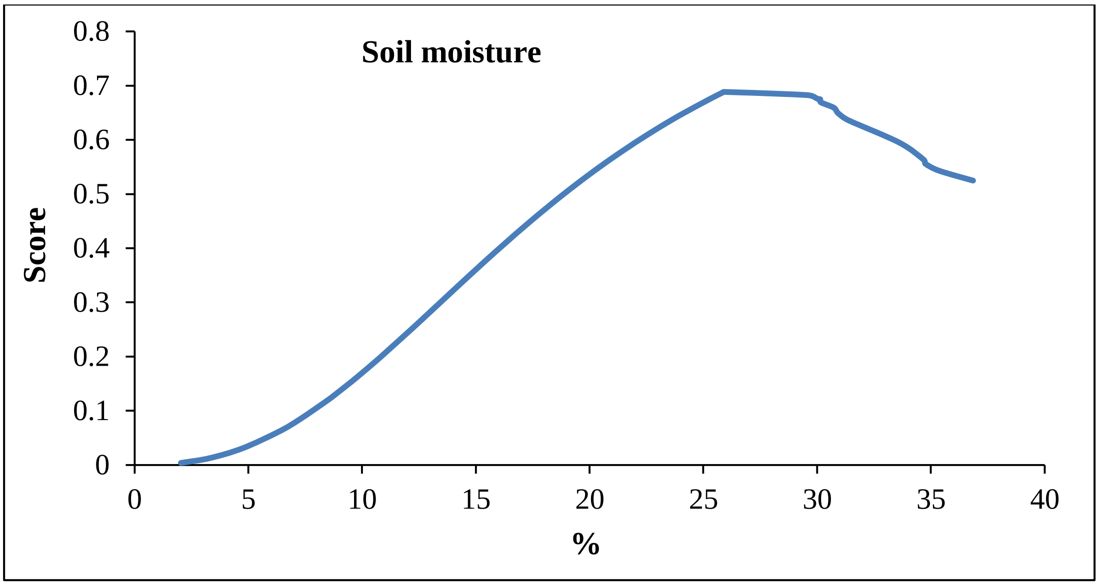

Fig. 19. ***Optimum*** **score curve for soil moisture**

4.4.3. Calculation of soil quality index

Soil quality index (SQI) was calculated using the method described by Doran and Parkin (1994):

Soil quality index = $\sum_{i=1}^{n} Wi \times Si$

where Si is the score for the subscripted variable and Wi is the weighing factor obtained from the PCA. Weighing factors were calculated by dividing per cent of variance by cumulative % of PCs having eigen value > 1 (Table 27,28).

Table 27. Weighing factor of each PC under AEU 5

PC	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Weights	0.43	0.17	0.1	0.09	0.08	0.07	0.05

Table 28.Weighing factor of each PC under AEU 9

PC	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7
Weights	0.24	0.2	0.15	0.13	0.1	0.09	0.08

The calculated soil quality indices (SQI) are represented in the table below. In the post flood soils of AEU 5, the soil quality index was found to be in the range of 0.42 to 0.76. The highest value was observed in the Vadakkekkara panchayat (0.76) and lowest value was observed in Nayarambalam panchayat (0.42). The highest mean of soil quality index was found in Chendamangalam (0.70) and lowest mean was found in Nayarambalam and Ezhikkara panchayats (0.47) (Table 29). The mean values of Kadamakkudy and Varapuzha were 0.59. Soil quality index mean values of Kottuvally, Chittatukkara, Ezhikkara, Mulavukad, Elamkunnapuzha, Njarakkal, Nayarambalam, Puthenvelikkara, Edavanakkad, Kuzhuppilly, Pallippuram Vadakkekkara and Chendamangalam panchayats were 0.53, 0.51, 0.47, 0.49, 0.56, 0.64, 0.47, 0.54, 0.55, 0.57, 0.48, 0.70 and 0.65 respectively.

Table 29. Soil quality index values of different panchayats of AEU 5

Panchayats	Soil quality index (SQI)	
	Mean ± SD	Range
Kadamakkudy	0.59 ± 0.13	0.46 - 0.73
Varapuzha	0.59 ± 0.13	0.45 - 0.72
Kottuvally	0.53 ± 0.1	0.43 - 0.63
Chittatukkara	0.51 ± 0.11	0.45 - 0.64
Ezhikkara	0.47 ± 0.04	0.43 - 0.52
Mulavukad	0.49 ± 0.1	0.46 - 0.52
Elamkunnapuzha	0.56 ± 0.15	0.42 - 0.65
Njarakkal	0.64 ± 0.007	0.63 - 0.64
Nayarambalam	0.47 ± 0.15	0.42 - 0.59
Puthenvelikkara	0.54 ± 0.02	0.52 - 0.56
Edavanakkad	0.55 ± 0.01	0.53 - 0.57
Kuzhuppilly	0.57 ± 0.1	0.55 - 0.58
Pallippuram	0.48 ± 0.06	0.43 - 0.53
Chendamangalam	0.70 ± 0.15	0.50 - 0.74
Vadakekkara	0.65 ± 0.08	0.55 - 0.76

In the post flood soils of AEU 9, the soil quality ranged from 0.39 to 0.92. The highest soil quality was observed in Aluva (0.92) and lowest value was observed in Edathala panchayat (0.39). The highest mean value of soil quality index was found in Sreemoolanagaram (0.79) and lowest mean value was noticed in Karumaloor (0.55) (Table 30). Soil quality index mean values of Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty, Parakkadav, Aluva, Karumaloor, Kunnukara, Choornikkara, Alangad and Edathala were 0.71, 0.79, 0.75, 0.78, 0.72, 0.62, 0.73, 0.55, 0.62, 0.63, 0.56 and 0.56 respectively.

Table 30. Soil quality index values of different panchayats of AEU 9

Panchayats	Soil quality index (SQI)	
	Mean ± SD	Range
Chengamanad	0.71 ± 0.09	0.64 - 0.85
Sreemoolanagaram	0.79 ± 0.06	0.73 - 0.88
Kanjoor	0.75 ± 0.09	0.64 - 0.85
Kalady	0.78 ± 0.008	0.77 - 0.79
Karukutty	0.72 ± 0.07	0.62 - 0.81
Parakkadav	0.62 ± 0.09	0.47 - 0.76
Aluva	0.73 ± 0.16	0.62 - 0.92
Karumaloor	0.55 ± 0.12	0.48 - 0.76
Kunnukara	0.62 ± 0.06	0.51 - 0.68
Choornikkara	0.63 ± 0.08	0.56 - 0.75
Alangad	0.56 ± 0.13	0.40 - 0.74
Edathala	0.56 ± 0.11	0.39 - 0.67

4.4.4. Relative soil quality index (RSQI)

The relative soil quality index (RSQI) was calculated using the method given by Karlen and Scott, 1994.

RSQI = computed SQI / theoretical maximum SQI × 100 where computed SQI is the value of each soil variable and theoretical maximum SQI is maximum SQI obtained by calculating with maximum score of each variable. RSQI values <50 % is categorized as poor, 50-70 % as medium and >70 % is categorized as good.

Table 31. Relative soil quality index values of different panchayats of AEU 5

Panchayats	Relative soil quality index (RSQI) (%)	
	Mean ± SD	Range
Kadamakkudy	50.86 ± 11.66	39.66 - 62.94
Varapuzha	51.15 ± 11.70	38.8 - 62.07
Kottuvally	45.69 ± 8.62	37.07 - 54.32
Chittatukkara	43.97 ± 7.36	37.63 - 53.68
Ezhikkara	40.82 ± 3.88	37.07 - 44.83
Mulavukad	42.07 ± 10.36	39.63 - 62.34
Elamkunnapuzha	48.27 ± 11.36	43.21 - 55.89
Njarakkal	55.61 ± 0.60	55.18 - 56.04
Nayarambalam	40.52 ± 11.15	37.06 - 67.35
Puthenvelikkara	46.55 ± 2.43	44.83 - 48.28
Edavanakkad	46.59 ± 0.2	45.63 - 47.52
Kuzhuppilly	47.05 ± 1.5	46.59 - 48.42
Pallippuram	41.37 ± 6.52	39.54 - 48.65
Chendamangalam	56.54 ± 12.07	37.88 - 71.22
Vadakekkara	54.36 ± 6.5	41.67 - 71.58

The relative soil quality index values are represented in the Table 31. The relative soil quality index values ranged from 37.07 per cent to 62.94 per cent under AEU 5 of Ernakulam district. The highest RSQI was obtained in Vadakkekkara panchayat (71.58%) and the lowest value obtained was 37.06 per cent in Nayarambalam panchayat. The highest RSQI mean was obtained in Chendamangalam panchayat (56.54%) and lowest RSQI mean was obtained in Nayarambalam

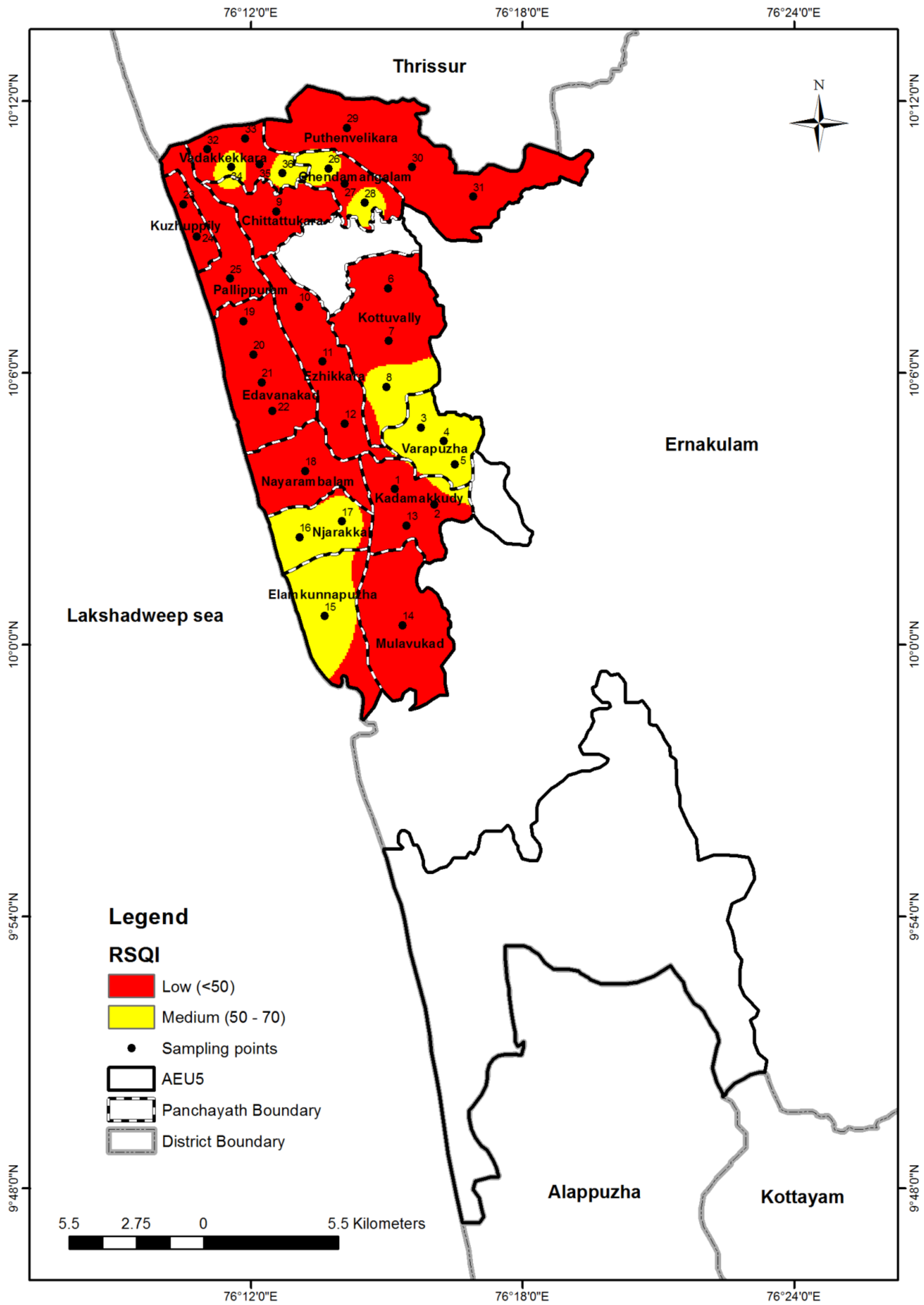

Plate 15. Spatial distribution of relative soil quality index (RSQI) in AEU 5

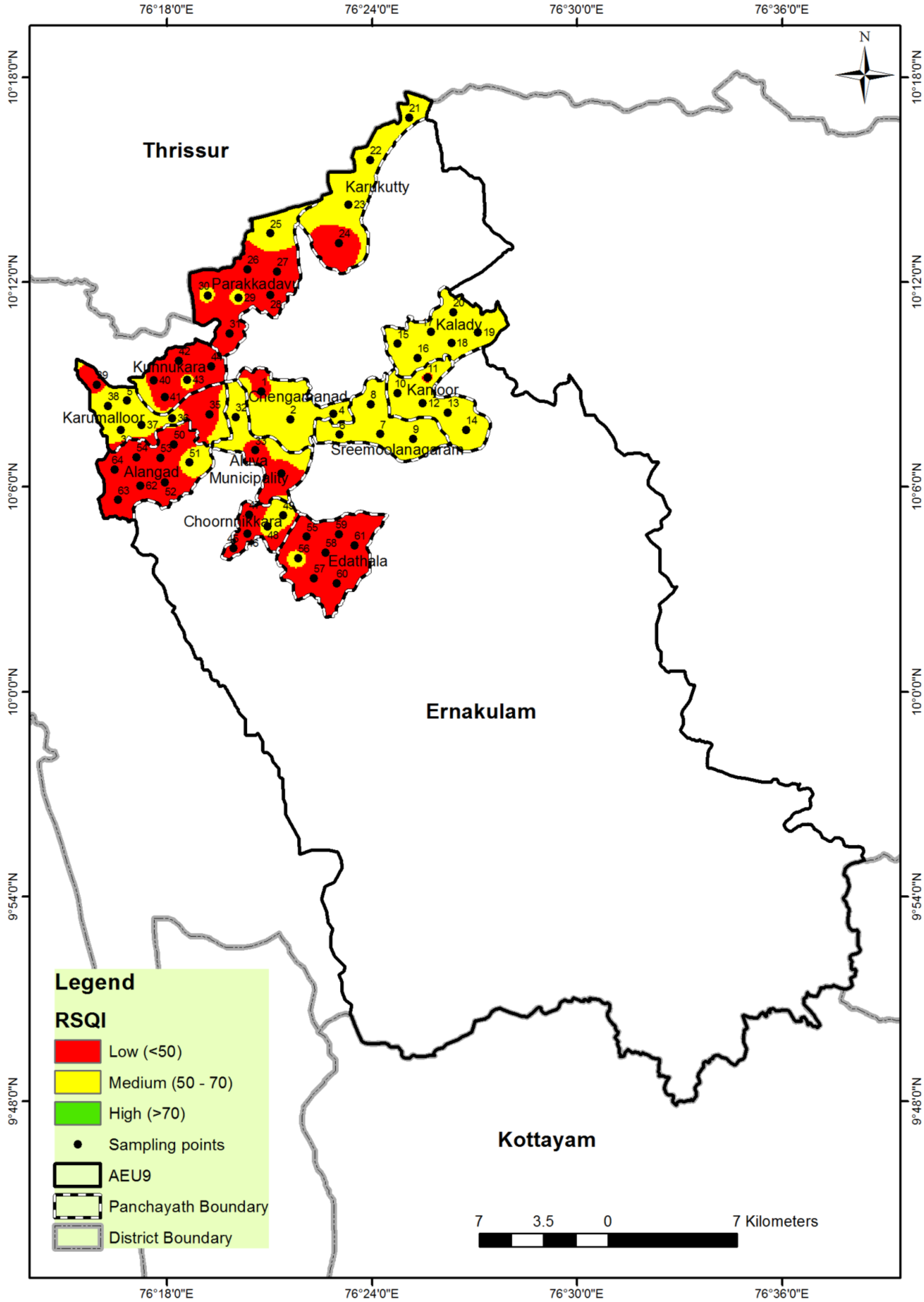

Plate 16. Spatial distribution of relative soil quality index (RSQI) in AEU 9

(40.52%). Out of 36 samples collected from AEU 5 of Ernakulam district 15 samples came under medium category in RSQI values, remaining 21 samples came under poor category in RSQI. By comparing RSQI means of different panchayats, Kadamakkudy, Varapuzha, Njarakkal, Chendamangalam and Vadakkekkara was rated as medium in soil quality. Kottuvally, Chittatukkara, Ezhikkara, Mulavukad, Elamkunnapuzha, Nayarambalam, Puthenvelikkara, Edavanakkad, Kuzhuppilly and Pallippuram recorded poor RSQI values. No panchayat recorded RSQI in good category (Table 31).

Table 32. Relative soil quality index values of different panchayats of AEU 9

Panchayats	Relative soil quality index (SQI)	
	Mean ± SD	Range
Chengamanad	54.17 ± 7.01	48.49 - 64.4
Sreemoolanagaram	60.30 ± 4.86	55.31 - 66.67
Kanjoor	56.82 ± 7.18	50 - 64.4
Kalady	59.09 ± 0.6	58.34 - 59.85
Karukutty	54.55 ± 5.96	46.97 - 61.37
Parakkadav	45.86 ± 7.08	35.61 - 57.58
Aluva	55.05 ± 12.70	46.97 - 69.7
Karumaloor	42.27 ± 9.12	36.37 - 57.58
Kunnukara	46.97 ± 5.02	38.64 - 51.52
Choornikkara	48.18 ± 6.63	42.43 - 56.82
Alangad	42.90 ± 10.16	30.31 - 56.07
Edathala	42.64 ± 8.62	29.55 - 50.76

Under AEU 9 the RSQI values varied from 29.55 per cent to 69.70 per cent. The highest RSQI value was found in Aluva (69.70%) and the lowest RSQI value was obtained in Edathala (29.55%). The highest mean RSQI was obtained in Sreemoolanagaram panchayat (60.30%) and lowest mean RSQI was obtained in Karumaloor (42.27%). By comparing RSQI mean of different panchayats, Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty and Aluva were rated as low in RSQI value and Alangad, Edathala, Parakkadav, Karumaloor, Kunnukara and Choornikkara recorded medium RSQI values. . No panchayat came under high RSQI category (Table 32).

4.5. NUTRIENT INDEX

The nutrient index of the soil was calculated for the soil samples using the following formula given by Ravikumar and Somashekar, (2013).

Nutrient index = (1× L) + (2 × M) + (3 ×H) / N

where L is the number of samples in low category, M is the number of samples in medium category, H is the number of samples in high category and N is the total number of samples. The nutrient index value greater than 2.33 is rated as high, 1.67-2.33 is rated as medium and less than 1.67 is rated as low category.

Under AEU 5, fertility status based on organic carbon and primary nutrients came under high category (NI >2.33), except in Chendamangalam and Vadakekkara panchayats (Table 33). In Chendamangalam and Vadakekkara panchayats, fertility status based on organic carbon and available N came under medium category (NI=1.67-2.33), fertility status based on available P and available K status were in high category (NI >2.33) (Table 33).

In AEU 9, fertility status of Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Parakkadav, Aluva, Karumaloor and Alangad panchayats based on organic carbon was rated as low category (NI <1.67). Fertility status of Karukutty, Parakkadav, Kunnukara, Choornikkara and Edathala based on organic carbon came under medium category (NI=1.67-2.33). Fertility status of Chengamanad, Kalady, Parakkadav, Karukutty, Aluva, Kanjoor, Karumaloor, Kunnukara, Choornikkara, Edathala and Alangad panchayats based on available N came under medium category (NI=1.67-2.33). In Sreemoolanagaram panchayat fertility status based on available N was in low category (NI <1.67). Fertility status of AEU 9 based on available P came under high category (NI >2.33). Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Karukutty, Parakkadav, Karumaloor and Kunnukara panchayats recorded fertility status in medium category based on available K (NI=1.67-2.33). Choornikkara, Edathala, Aluva and Alangad panchayats registered low fertility status based on available K (NI <1.67) (Table 34).

Table 33. Nutrient index of organic carbon, available nitrogen, available phosphorus and available potassium in AEU 5

Panchayats	Organic carbon	Available nitrogen	Available phosphorus	Available Potassium
Kadamakkudy	3	2.33	3	3
Varapuzha	3	3	3	3
Kottuvally	2.66	3	3	3
Chittatukkara	3	2.5	3	3
Ezhikkara	3	3	3	3
Mulavukad	3	2.5	3	3
Elamkunnapuzha	3	2.6	3	3
Njarakkal	3	2.5	3	3
Nayarambalam	2.5	2.5	3	3
Puthenvelikkara	3	3	3	3
Edavanakkad	2.3	3	3	3
Kuzhuppilly	3	2.5	3	3
Pallippuram	2.5	2.5	3	3
Chendamangalam	2	2	2.83	1.66
Vadakekkara	2	1.8	3	1.6

Table 34. Nutrient index of organic carbon, available nitrogen, available phosphorus and available potassium in AEU 9

Panchayats	Organic carbon	Available nitrogen	Available phosphorus	Available potassium
Chengamanad	1.25	2	2.35	1.75
Sreemoolanagaram	1.4	1.4	3	2
Kanjoor	1.4	1.8	3	2
Kalady	1.33	2	2.66	2.16
Karukutty	2.33	2	3	1.75
Parakkadav	2.14	1.85	3	1.71
Aluva	1.66	2.33	2.66	1.66
Karumaloor	1.6	2	2.8	2.2
Kunnukara	2	1.8	3	2.2
Choornikkara	2	2	3	1.4
Alangad	1.62	1.87	2.87	1.25
Edathala	1.85	1.85	3	1.42

4.6. PREPARATION OF GIS MAPS

The RSQI value generated after the soil quality assessment of the soil samples collected from different locations were used for the preparation of geo-referenced thematic maps (Plate 1-16). Maps were prepared using ArcGIS 10.5.1 software.

Discussion

DISCUSSION

The present study was undertaken to evaluate the post flood scenario in AEU 5 and AEU 9 of Ernakulam district and develop GIS maps. Soil samples from the flood affected areas of AEU 5 and AEU 9 were collected and characterised for physical, chemical and biological attributes. Principal component analysis was done with 23 attributes which resulted in 7 principal components. Minimum dataset was developed using selected indicators. Soil quality index (SQI) and relative soil quality index (RSQI) were computed using MDS. The results of the entire experiments are discussed in this chapter with supporting studies from the literature.

5.1. PHYSICAL ATTRIBUTES

5.1.1. Bulk density

The bulk density of soil samples collected from AEU 5 had a value below 1.2 Mg m^{-3} for 80.55 per cent of the samples, 1.2 to 1.4 Mg m^{-3} for 16.66 per cent of the samples and 1.4 to 1.6 Mg m^{-3} for 2.7 per cent of the samples (Fig. 20). Joseph (2014) reported that the mean value of bulk density in *Pokkali* soils prior to flood varied from 0.56 to 1.17 Mg m^{-3} while in current study, analysis of post flood soils revealed that bulk density varied from 0.23 Mg m^{-3} to 1.53 Mg m^{-3}. Low bulk density was observed due to the high organic matter content in *Pokkali* soils. Similar to the present study, Sasidharan (2004) also reported low bulk density value of 0.67 Mg m^{-3} in *Pokkali* soils.

The soil samples collected from AEU 9 had a bulk density value below 1.2 Mg m^{-3} for 20.31 per cent of the samples, 1.2 to 1.4 Mg m^{-3} for 46.87 per cent of samples, 1.4 to 1.6 Mg m^{-3} for 26.56 per cent of samples and values greater than 1.6 Mg m^{-3} for 6.25 per cent of the samples (Fig. 20). Chaudhari *et al.,* (2013) stated that the bulk density of soil had a negative correlation with organic carbon content (r= -0.976*) and porosity (r= -0.885*).

5.1.2. Particle density

The particle density of soil samples collected from AEU 5 recorded a value below 2.2 Mg m^{-3} for 24 per cent of samples, 2.2 to 2.4 Mg m^{-3} for 32 per cent of samples, 2.4 to 2.6 Mg m^{-3} for 24 per cent of samples and greater than 2.6 Mg m^{-3} for 20 per cent of the samples (Fig. 21). The particle density of soils under AEU 9 showed a value below 2.2 Mg m^{-3} for 6.6 per cent of samples, 2.2 to 2.4 Mg m^{-3} for 28 per cent of samples, 2.4 to 2.6 Mg m^{-3} for 46.6 per cent of samples and greater than 2.6 Mg m^{-3} for 17.33 per cent of the samples (Fig. 21). Particle density depends mainly on the mineral composition of the soil. Higher value for particle density might be due to presence of heavy minerals in the soil and lower value for particle density might be due to the organic matter content in the soil (Ruhlmann *et al.,* 2006).

5.1.3. Porosity

Under AEU 5, 5.55 per cent of the soil samples recorded porosity in between 30 to 70 per cent, 25 per cent of samples were in between 50 to 70 per cent and remaining 69.44 per cent of samples were having greater than 70 per cent porosity (Fig. 22). This could be due to the high organic matter content and clay content in the soil. In AEU 9, 1.56 per cent of the samples were below 30 per cent porosity, 56.25 per cent of samples were in between 30 to 50 per cent, 42.18 per cent of samples were in between 50 to 70 per cent porosity (Fig. 22). The plant root penetration, number of root hairs and root length depends on soil porosity (Haling *et al.,* 2014). Porosity had a significant negative correlation with bulk density (r= -0.940**) and (r= -0.927**) under AEU 5 and AEU 9 respectively. Chaudhari *et al.,* (2013) also reported a strong negative correlation between porosity and bulk density.

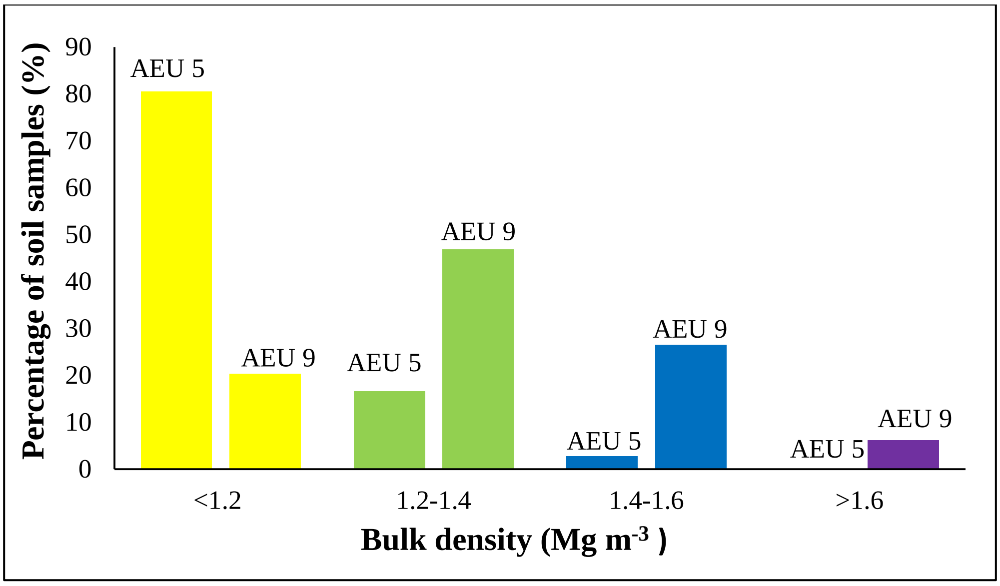

Fig.20. Percentage distribution of bulk density in the post flood soils of AEU 5 and 9 of Ernakulam district

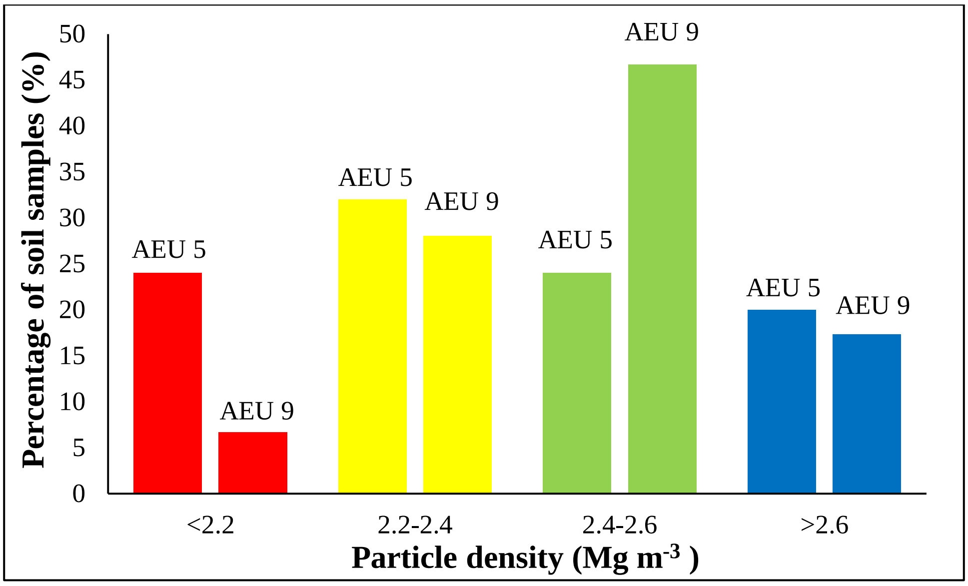

Fig.21. Percentage distribution of particle density in the post flood soils of AEU 5 and 9 of Ernakulam district

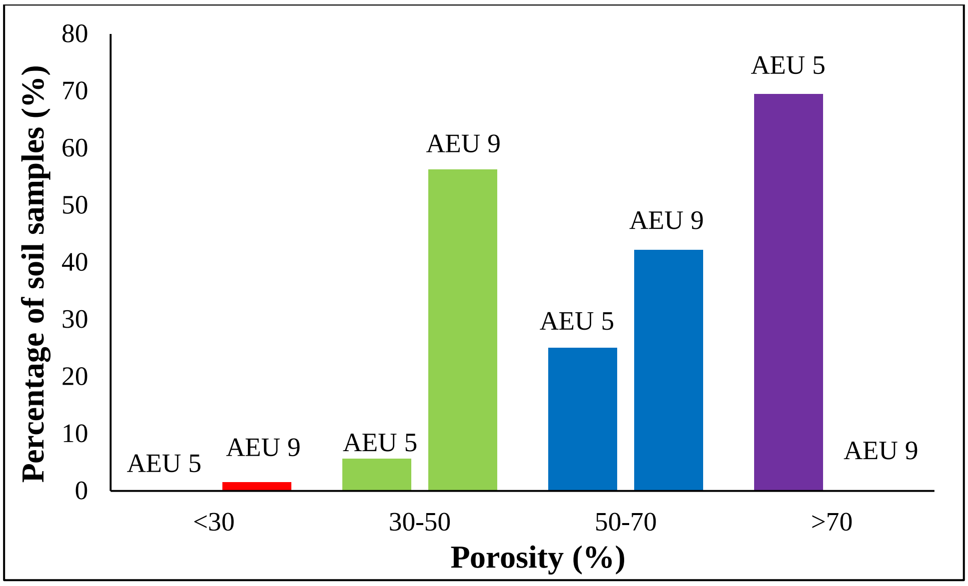

Fig.22. Percentage distribution of porosity in the post flood soils of AEU 5 and 9 of Ernakulam district

5.1.4. Maximum water holding capacity

Percentage distribution showed 2.77 per cent of the samples were having below 30 per cent MWHC, 25 per cent of them were in between 30 to 50 per cent, 52.77 per cent of them were in between 50 to 70 per cent and 19.44 per cent of them were greater than 70 per cent MWHC in AEU 5. While under AEU 9, 15.62 per cent of the samples were below 30 per cent and 84.37 per cent were in between 30 to 50 per cent MWHC (Fig. 23). Water holding capacity of the soils depends on the number of pores, pore size distribution and the specific surface area of the soil. Clayey soils have more surface area and more number of micropores compared to sandy soils; this might be the reason that *Pokkali* soils have more water holding capacity. Soil may vary with their water holding capacity according to their structure, texture and bulk density which indirectly affect pore size distribution (Vengadaramana and Jashothan, 2012). With addition of organic matter, specific surface area increases thus resulting in increased water holding capacity (Leu *et al.*, 2010).

5.1.5. Soil moisture content

Out of 36 samples collected from AEU 5, 8.33 per cent of the samples recorded 10 to 15 per cent soil moisture, 16.66 per cent of the samples showed 15 to 25 per cent and 75 per cent of the samples were having greater than 25 per cent soil moisture content (Fig. 24). In AEU 9, out of 64 samples 12.5 per cent of samples were having less than 10 per cent soil moisture, 17.18 per cent of samples were in between 10 to 15 per cent, 48.43 per cent in high and 21.87 per cent were in very high range (Fig. 24). Soil moisture had an effect on porosity and water holding capacity. Soil texture, organic carbon had significant effects on soil moisture (Moyano *et al.*, 2012). *Pokkali* soils are clayey in texture and had higher organic carbon content; this might be the reason for the higher soil moisture than the soil from AEU 9.

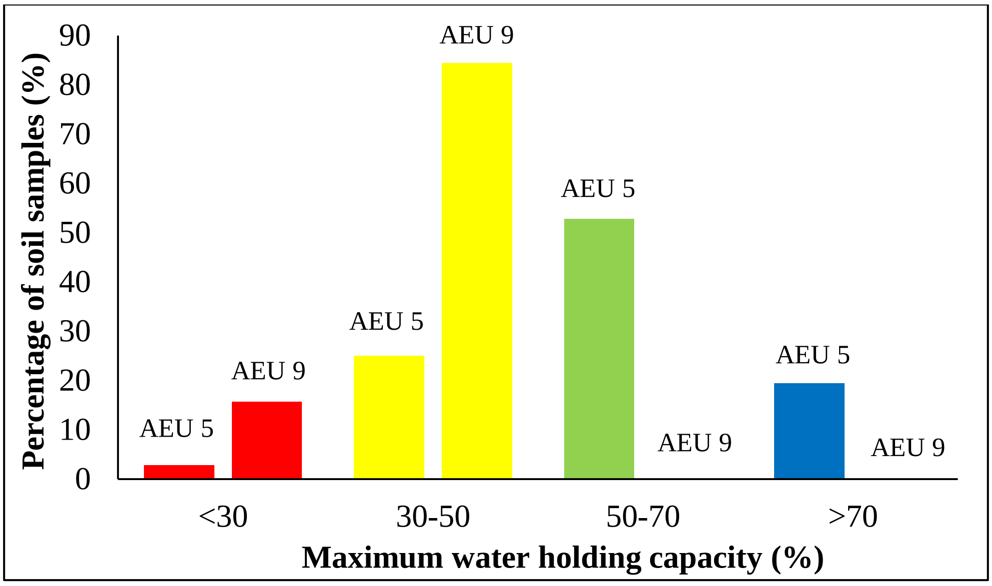

Fig.23. Percentage distribution of maximum water holding capacity in the post flood soils of AEU 5 and 9 of Ernakulam district

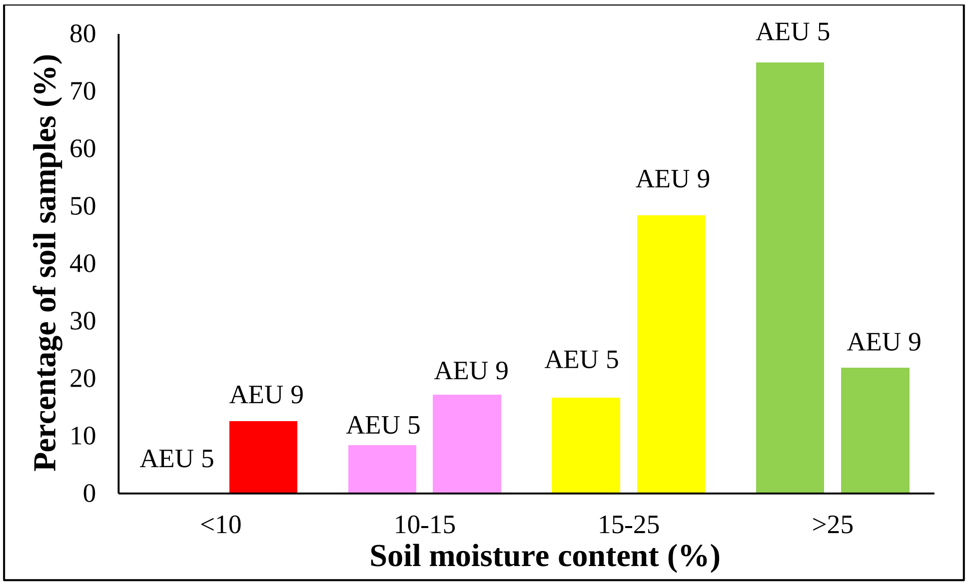

Fig.24. Percentage distribution of soil moisture in the post flood soils of AEU 5 and 9 of Ernakulam district

5.2. CHEMICAL ATTRIBUTES

5.2.1. Soil reaction

In post flood soils under AEU 5 the soil pH varied widely, 8 per cent of the samples were in ultra-acidic class, 8 per cent in extremely acidic, 8 per cent in very strongly acidic, 20 per cent in strongly acidic, 12 per cent in moderately acidic, 36 per cent in slightly acidic and 8 per cent in neutral class (Fig. 25). The soil pH after flood varied from 3.04 to 7.22 and 44 per cent of the samples came under slightly acidic to neutral class. Soil reaction prior to flood showed that 70 per cent of the soils came under moderately acidic to neutral category (pH 5.6-7.3) (GoK, 2013). The mean value of pH prior to flood ranged from 5.69 to 7.26 in *Pokkali* soils (Joseph, 2014). In comparison with pre flood data, soil reaction showed similar range after flood. Soil samples were collected during June which is low saline phase and due to heavy rainfall soil acidity was found to be lowered. Krishnani *et al.* (2014) reported that, paddy shrimp culture in *Pokkali* soils recorded acidic soil with pH in the range of 3.76 to 5.60. Sasidharan (2006) reported that, tidal action significantly increased soil pH. Neutralisation of acidity in acid sulphate soils with the seawater intrusion was reported by Wong *et al*, (2010).

Percentage distribution of post flood soil samples of AEU 9 showed that 20 per cent of the samples came under very strongly acidic class, 30.66 per cent were strongly acidic, 32 per cent were moderately acidic, 14.66 per cent were slightly acidic and 2.66 per cent were in neutral class (Fig. 25). Pre flood data also showed similar results, 57 per cent of the samples came under very strongly acidic to strongly acidic (4.5-5.5) (GoK, 2013). Leaching of exchangeable bases due to heavy rainfall could be the reason for low pH. Continuous use of fertilizers can be also contributed to low pH (Emiru and Gebrekidan, 2013).

5.2.2. Electrical Conductivity

It was found that 16.66 per cent of soil samples were non saline, 8.33 per cent were slightly saline, 19.44 per cent were moderately saline and 55.55 per cent of them were highly saline in soils collected from AEU 5 (Fig. 26). Pre flood data of *Pokkali* soils showed that mean EC values varied from 2.40 to 4.05 dS m^{-1} (Joseph, 2014). The EC of soils after flood ranged from 0.19 to 7.72 dS m^{-1} and 16.66 per cent of the soil samples were non saline because they were collected from uplands of AEU 5. Seawater inundation and backwaters are the major reason for the high EC values. Krishnani *et al.* (2011) reported that, paddy shrimp culture land area recorded EC values from 4.15 to 7.38 dS m^{-1}. Shylaraj *et al.* (2013) reported that, EC values varied from 0.001 to 7.80 dS m^{-1} during low saline phase and 0.10 to 9.80 dS m^{-1} during high saline phase in *Pokkali* spoils. While in AEU 9 all the samples were found non saline (Fig. 26). There was not much difference in EC among different sites in AEU 9. This indicated that, no remarkable soluble salt accumulation was noticed. Soil samples were collected after heavy rain; this might have washed out the excess salts from the soil (Jackson *et al.*, 1997).

5.2.3. Exchangeable acidity

Out of 36 soil samples collected from AEU 5, 88.88 per cent of the samples were below 1 cmol(+)kg^{-1}, 5.55 per cent of them were in between 1 to 2 cmol(+)kg^{-1} and 5.55 per cent of them were greater than 2 cmol(+)kg^{-1}. *Pokkali* soils have low exchangeable acidity even though they have low pH and this could be due to high base saturation in the soils (Joseph, 2014). Out of 64 soil samples collected from AEU

9, 87.5 per cent of the samples showed exchangeable acidity below 1 cmol(+)kg^{-1}, 10.93 per cent of them were in between 1 to 2 cmol(+)kg^{-1} and 1.56 per cent of them were greater than 2 cmol(+)kg^{-1}(Fig. 27). This could be due to the very strongly to moderately acidic pH of the soil.

5.2.4. Effective cation exchange capacity

The effective cation exchange capacity in AEU 5 showed that 2.77 per cent of the samples recorded values below 10 cmol(+)kg^{-1}, 22.22 per cent were in between 10 to 16 cmol(+)kg^{-1} and 75 per cent of them were above 16 cmol(+)kg^{-1}. High effective cation exchange capacity in *Pokkali* soils could be due to the high organic matter content and clay content in the soil. Also it might be due to the presence of large amount of Na^{+} and K^{+} cations in soil which is soluble form and it is easily extracted by $BaCl_2$ (Santhosh, 2013). In AEU 9, 7.8 per cent of the samples were below 10 cmol(+)kg^{-1}, 85.93 per cent of the samples were in between 10 to 16 cmol(+)kg^{-1} and 6.25 per cent of the samples were greater than 16 cmol(+)kg^{-1} (Fig. 28). Low effective cation exchange capacity might be due to acidic pH of the soil.

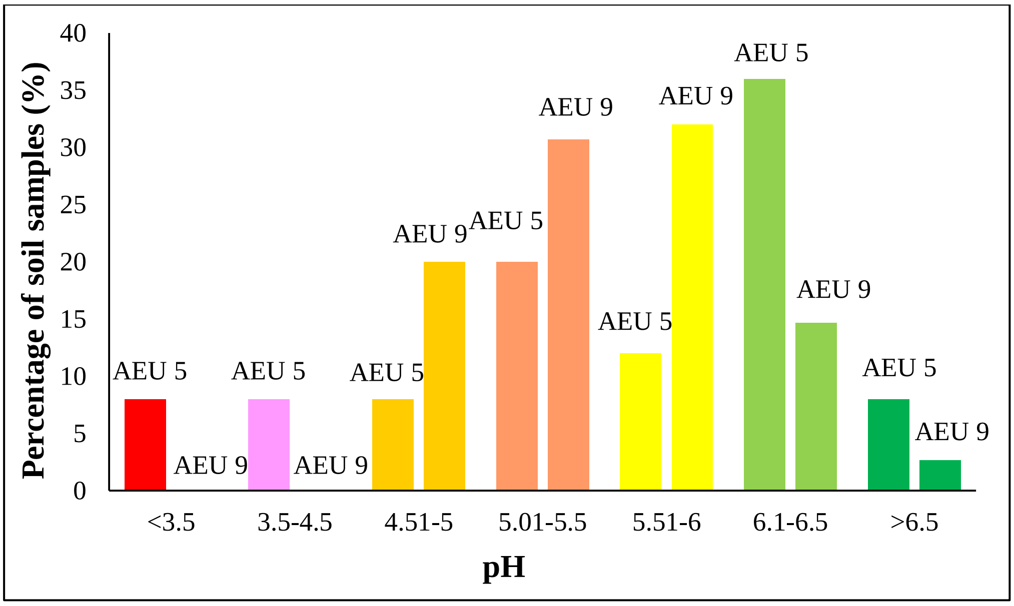

Fig.25. Percentage distribution of pH in the post flood soils of AEU 5 and 9 of Ernakulam district

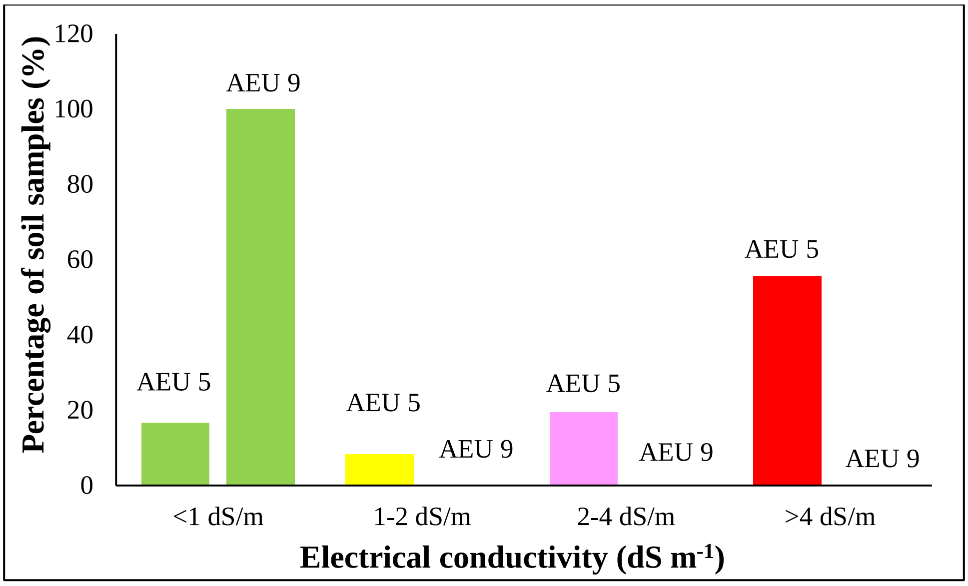

Fig.26. Percentage distribution of electrical conductivity in the post flood soils of AEU 5 and 9 of Ernakulam district

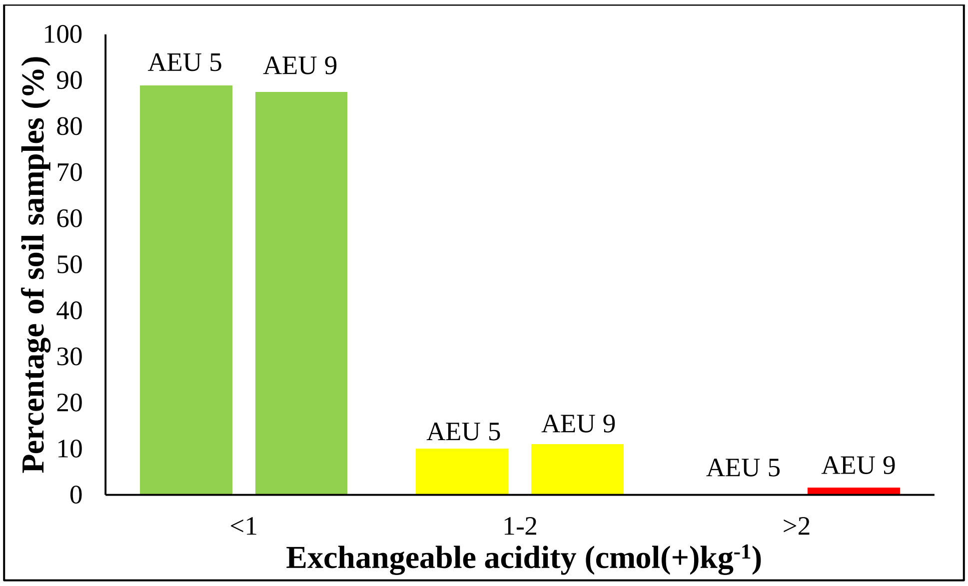

Fig.27. Percentage distribution of exchangeable acidity in the post flood soils of AEU 5 and 9 of Ernakulam district

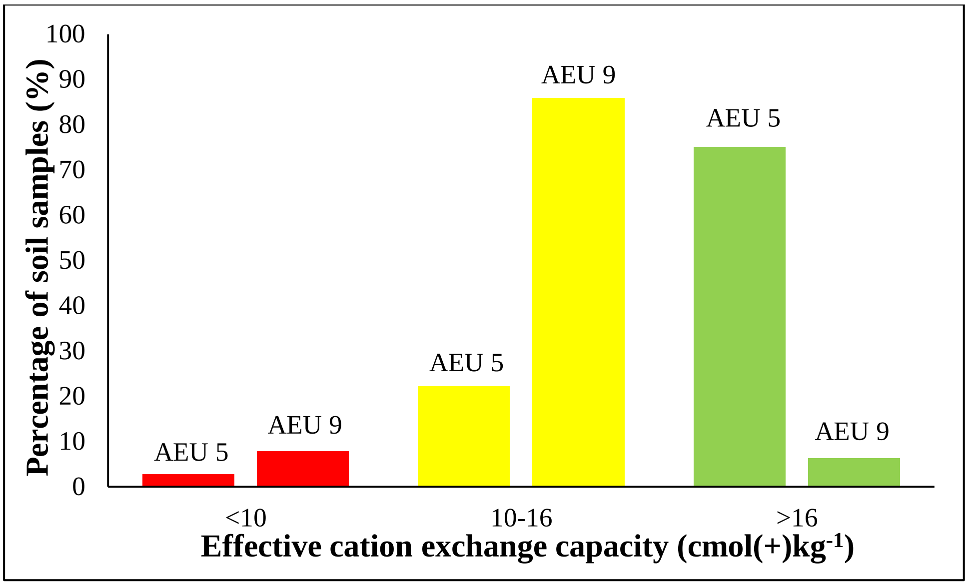

Fig.28. Percentage distribution of effective cation exchange capacity in the post flood soils of AEU 5 and 9 of Ernakulam district

5.2.5. Available nitrogen

The available N was found low in 5.55 per cent of samples, medium in 50 per cent of the samples and high in 41.66 per cent of the samples in AEU 5 (Fig. 29). Joseph (2014) also stated that, the available N status in *Pokkali* comes under medium category even though the organic carbon content is higher. This could be due to the slow decomposition of organic matter under flooded conditions. In submerged soils the formation and loss of nitrate is common and it occurs within the adjoining aerobic and anaerobic zones (Buresh *et al.,* 2008). The available N content in the post flood soil samples of AEU 9 was low in 7.81 per cent of the samples, medium in 87.5 per cent of the samples and high in 4.68 per cent of the samples (Fig. 29). Nitrogen status is mainly governed by organic carbon content in the soil (Verma *et al.,* 1980).

5.2.6. Available phosphorus

The available P recorded medium in 5.55 per cent of the samples and high in 94.44 per cent of the samples under AEU 5 of Ernakulam district (Fig. 30). Pre flood data in AEU 5 showed that 84 per cent of the samples were having high available P status (GoK, 2013) and Joseph (2014) also reported that high status of available P in

Pokkali soils. Available P recorded high status after the flood. Due to the submergence of the soil, the pH of acidic soil increased to near neutral pH and resulted in higher availability of phosphorus. Diya and Sreelatha (2018) also observed higher available P status in *Pokkali* soils. Tidal influence also contributes to high P content in *Pokkali* soils.

In the post flood soils the available P was observed low in 3.12 per cent of the samples, medium in 6.25 per cent of the samples and high in 90.62 per cent of the samples in AEU 9 (Fig. 30). Pre flood soil data in AEU 9 showed that 68 per cent of the samples were high in available P status. There was a slight increase in available P in the soil after flood. Sedimentation after floods might be reason for high P status. Addition of organic manures also contributes to higher available P in the soils (Emiru and Gebrekidan, 2013).

5.2.7. Available potassium

The available K was found medium in 13.88 per cent of the samples and high in 86.11 per cent of the samples in post flood situation under AEU 5 (Fig. 31). Joseph (2014) also reported higher status of available K in *Pokkali* soils prior to flood. The status of available K did not change after the flood. This might be due to the seawater intrusion. Sasidharan (2006) also reported that, seawater inundation significantly increased the available potassium content in *Pokkali* soils. Tidal action on the *Pokkali* soils contributes to increased available K. The available K content of *Pokkali* soils varied from 108 to 2063.43 kg ha^{-1} as reported by Joseph (2014). Submergence of *Pokkali* soils increased the K content of the soil (Kuruvila, 1974) and surface soils of *Pokkali* fields were found to be rich in K content (Samikutty, 1977).

The available K in the post flood soils was recorded low in 37.5 per cent of the samples, medium in 48.43 per cent of the samples and high in 14.06 per cent of the samples under AEU 9 (Fig. 31). Prior to flood 40 per cent of the samples were medium and 41 per cent of the samples were in high in available K (GoK, 2013). The decrease in sufficiency level of K after flood might be due to the leaching of K after heavy rainfall. Decrease in organic matter content in soil might also the reason for low K content (Gairola *et al.*, 2012). Boruah and Nath (1992) reported that, there is a positive relationship between available K and organic matter. The layer of organic matter gives site for retention of K in the soils.

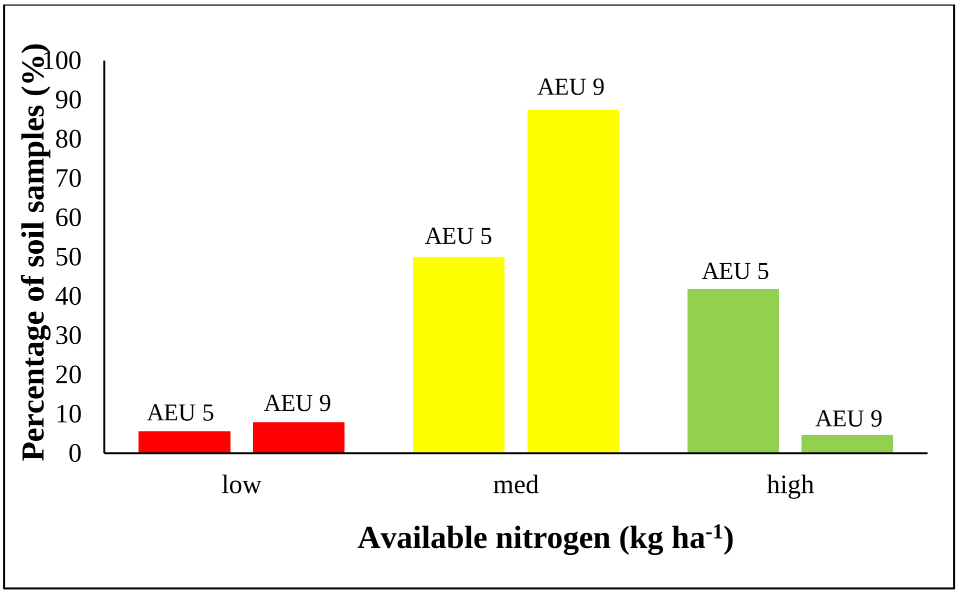

Fig.29. Percentage distribution of available nitrogen in the post flood soils of AEU 5 and 9 of Ernakulam district

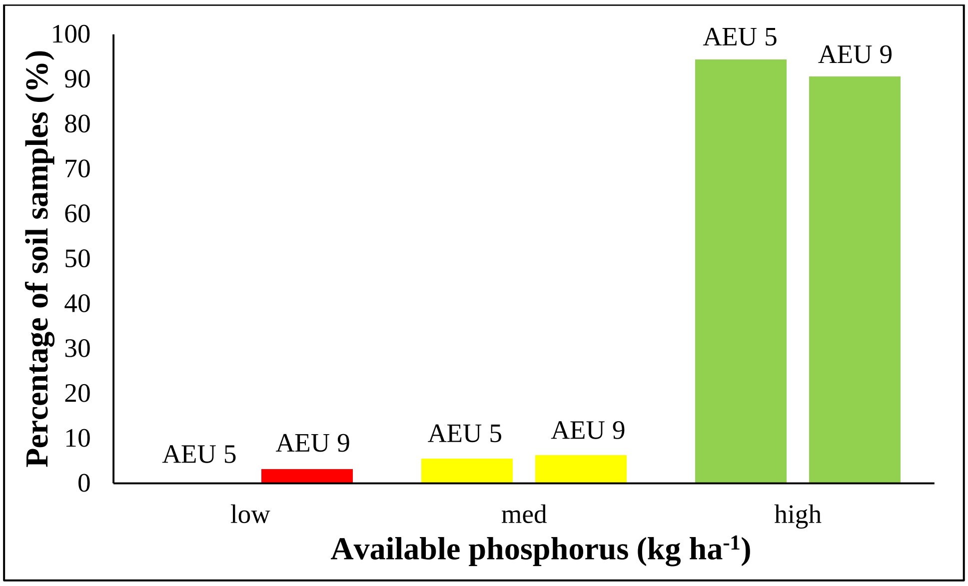

Fig.30. Percentage distribution of available phosphorus in the post flood soils of AEU 5 and 9 of Ernakulam district

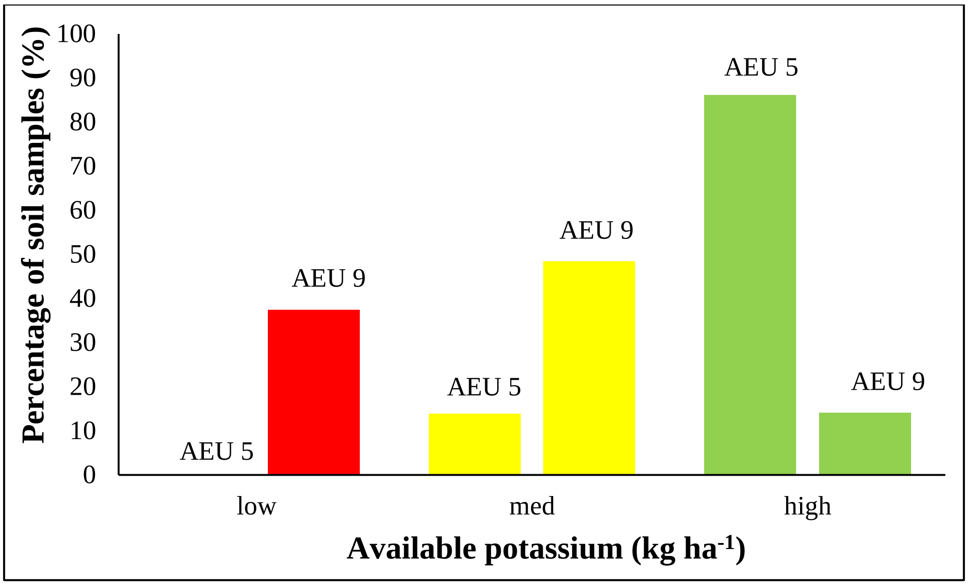

Fig.31. Percentage distribution of available potassium in the post flood soils of AEU 5 and 9 of Ernakulam district

5.2.8. Available calcium

The available Ca content in the post flood soil samples from AEU 5 was found sufficient in 94.44 per cent of the samples and deficient in 5.55 per cent of the samples (Fig. 32). Pre flood data showed that 70 per cent of the samples were sufficient in available Ca (GoK, 2013) and high Ca content (>300 mg kg^{-1}) in *Pokkali* soils was reported by Joseph (2014). Higher available Ca in *Pokkali* soils could be due to the deposition of Ca rich exuvia of prawns (Tacon, 1987). The available Ca found doubled after the harvest of prawn culture. The Ca is found in water soluble and organically complexed forms in *Pokkali* soils, so that Ca content is directly influenced by tidal action and organic matter content (Bhindu, 2017). Anilkumar and Annie (2010) reported that, the Ca content during low saline phase was 76 to 256 mg kg^{-1} in *Pokkali* fields.

The available Ca content was found sufficient in 62.5 per cent of the samples and deficient in 37.5 per cent of the samples in post flood soils under AEU 9. Pre flood data showed that 70 per cent of the samples were sufficient in available Ca

(GoK, 2013) (Fig. 32). This might be due to the application of sufficient lime in the soils (Nithya, 2013).

5.2.9. Available magnesium

The available Mg after flood was found to be deficient in 80.55 per cent of the samples and sufficient in 19.44 per cent of the samples under AEU 5 of Ernakulam district (Fig. 33). Prior to flood, available Mg was deficient in 72 per cent of the samples (GoK, 2013) and Joseph (2014) also reported the deficiency of Mg in *Pokkali* soils under different land use systems. *Pokkali* soils were found deficient in available Mg (<120 mg kg^{-1}), even though there is seawater intrusion. Aryalekshmi (2016) noticed that, available Mg in *Pokkali* soils was 26.17 mg kg^{-1}. Mg may be in unavailable form or adsorbed in soil so it cannot be extracted using neutral normal ammonium acetate (Joseph, 2014).

Pre flood data showed that 61 per cent of the samples were deficient in available Mg (GoK, 2013). The available Mg was found deficient in all the samples collected from AEU 9 in post flood situation (Fig. 33) and the deficiency level was found to be increased. This might be due to the acidic nature of the soils (Raghunath, 2017).

5.2.10. Available sulphur

In AEU 5**,** all the soil samples were extremely high in available S status (>10 mg kg^{-1}) (Fig. 34). Prior to flood available S was sufficient in 86 per cent of the samples (GoK, 2013) and high S content was observed in *Pokkali* soils, the mean value ranged from 54.34 to 133.73 mg kg^{-1} (Joseph, 2014). The available S in the post flood soils varied from 7.07 mg kg^{-1} to 241.73 mg kg^{-1}. Higher available S was reported in *Pokkali* lands due to the acid sulphate nature of the soil (Santhosh, 2013). Kuruvila (1974) reported the available S content in *Pokkali* soils was 242 $mgkg^{-1}$.

The available S was found deficient in 13.88 per cent of the samples and sufficient in 86.11 per cent of the samples under AEU 9 in the post flood situation (Fig. 34). Majority of the soil samples were having higher level of available S. Prior to flood, available S was sufficient in 80 per cent of the samples (GoK, 2013).

Sulphur status in the soil did not change after flood; this might be due to the organic matter addition in the soil. There is an association of organic matter with S in the soil (Gairola *et al.,* 2012). Addition of S containing fertilizers, especially factomphos and plant protection chemical also contributes to S content in the soil (Raghunath, 2017).

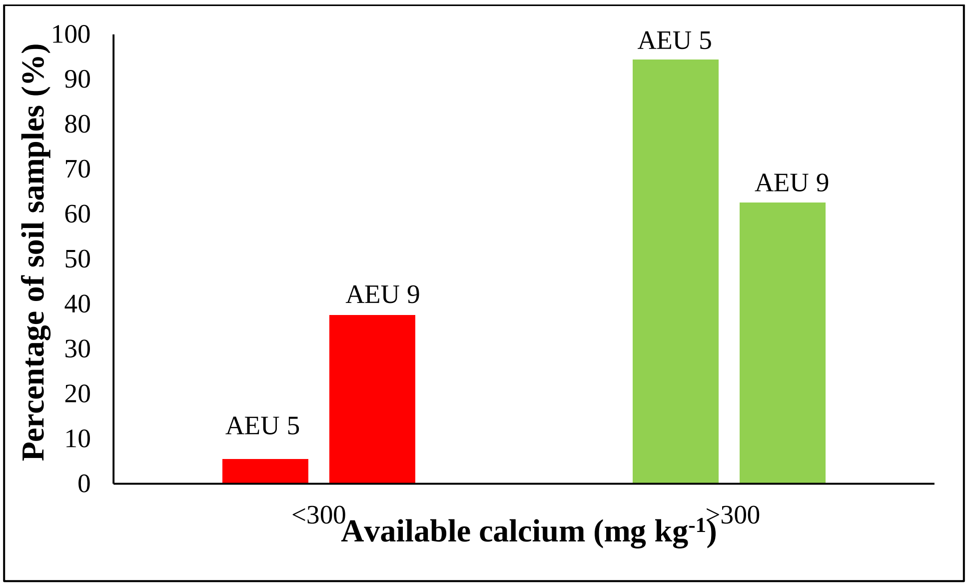

Fig.32. Percentage distribution of available calcium in the post flood soils of AEU 5 and 9 of Ernakulam district

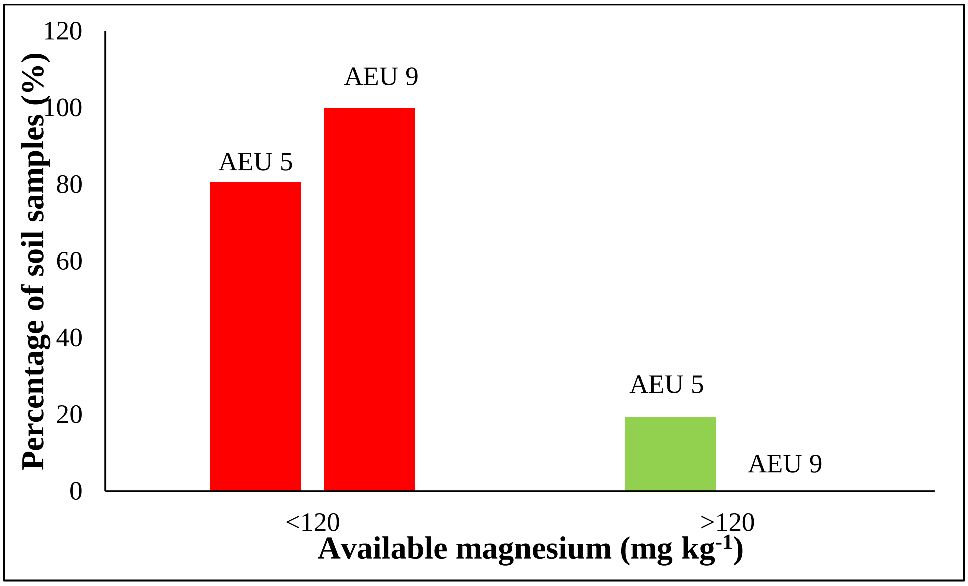

Fig.33. Percentage distribution of available magnesium in the post flood soils of AEU 5 and 9 of Ernakulam district

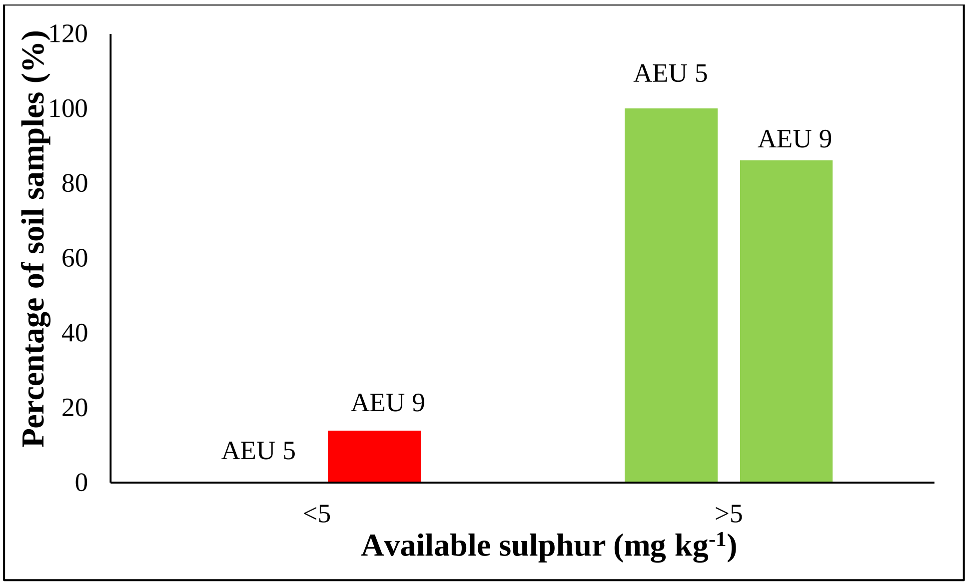

Fig.34. Percentage distribution of available sulphur in the post flood soils of AEU 5 and 9 of Ernakulam district

5.2.11. Available iron

Available Fe showed extreme toxicity in all the soil samples collected from AEU 5 after flood (Fig. 35). Similar findings were reported by Joseph (2014) in *Pokkali* soils under different land uses prior to flood. Shylaraj *et al.* (2013) reported that, available Fe content recorded was 171 to 2321 mg kg^{-1} in *Pokkali* soils. The available Fe was 1727 mg kg^{-1} in *Pokkali* soils as reported by Sasidharan (2004). Available Fe content in *Pokkali* soils was found to be high at both rice harvesting and prawn harvesting stages (Diya and Sreelatha, 2018). During submergence the availability of Fe and Mn will increase (Ponnamperuma, 1972). Under AEU 9, all the samples were found to be in sufficient range. This is due to the inherent acidic nature and laterite soil type prevalent in Kerala soil.

5.2.12. Available manganese

All the post flood soil samples showed toxicity of available Mn in AEU 5 (Fig. 36). Pre flood data also showed toxicity of available Mn in *Pokkali* soils (Joseph, 2014). This may be due to the flooding of the soil. During submergence, the availability of Fe and Mn will increase (Ponnamperuma, 1972). Shylaraj *et al.* (2013) also reported that, available Mn was 2 to 26 mg kg^{-1} during low saline phase and 1 to

34 mg kg^{-1} during high saline phase. Tisdale *et al.* (1985) stated that submergence and water logging increases availability of soluble Mn. Available Mn content in *Pokkali* soil was found high at both rice harvesting and prawn harvesting stages (Diya and Sreelatha, 2018). The available Mn under AEU 9 was found deficient in 2.66 per cent of the samples and sufficient in 97.33 per cent of the samples (Fig. 36). Higher Mn content could be due to the acidic pH of the soil and laterite soil type prevalent in Kerala soil (Schulte and Kelling, 2004). The chelation of organic compounds released during the decomposition of organic matter contributes to high Mn content in the soils (Raghunath, 2017).

5.2.13. Available zinc

In the post flood soils of AEU 5, all the samples showed higher levels of available Zn (Fig. 37). Pre flood data showed that 92 per cent of the samples were adequate (GoK, 2013) and available Zn was reported high in *Pokkali* soils by Joseph (2014). Anilkumar and Annie (2010) found that, available Zn was in the range of 2 to 173 mg kg^{-1} in *Pokkali* soils. Available Zn content in *Pokkali* soils were found to be high at both rice harvesting and prawn harvesting stages (Diya and Sreelatha, 2018). Mohan (2016) also reported higher available Zn in *Pokkali* soils. In the post flood soils the available Zn was recorded deficient in 17.18 per cent of the samples and sufficient in 82.81 per cent of the samples from AEU 9 (Fig. 37). Prior to flood it was sufficient in 87 per cent of the samples (GoK, 2013). This might be due to the acidic nature of the soil (Schulte and Kelling, 2004).

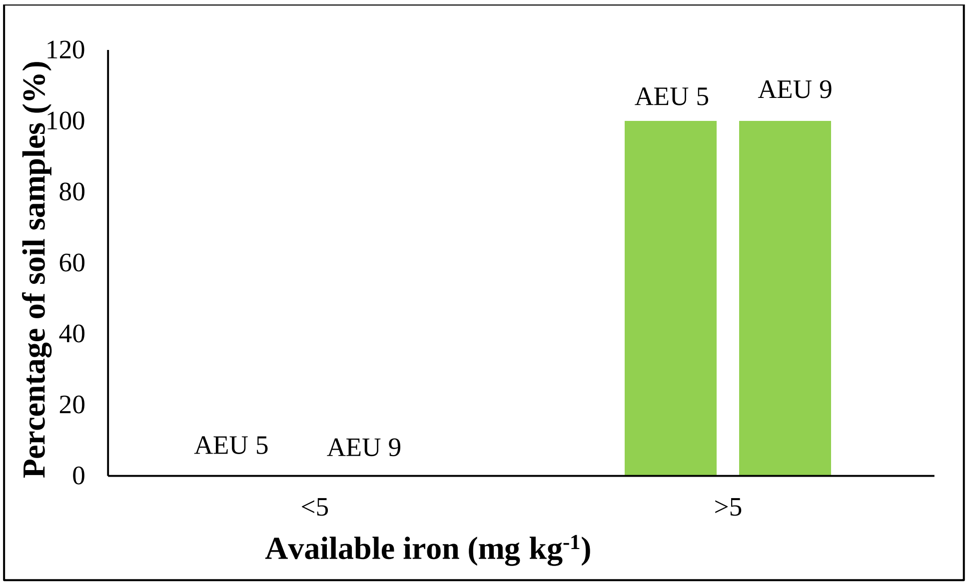

Fig.35. Percentage distribution of available iron in the post flood soils of AEU 5 and 9 of Ernakulam district

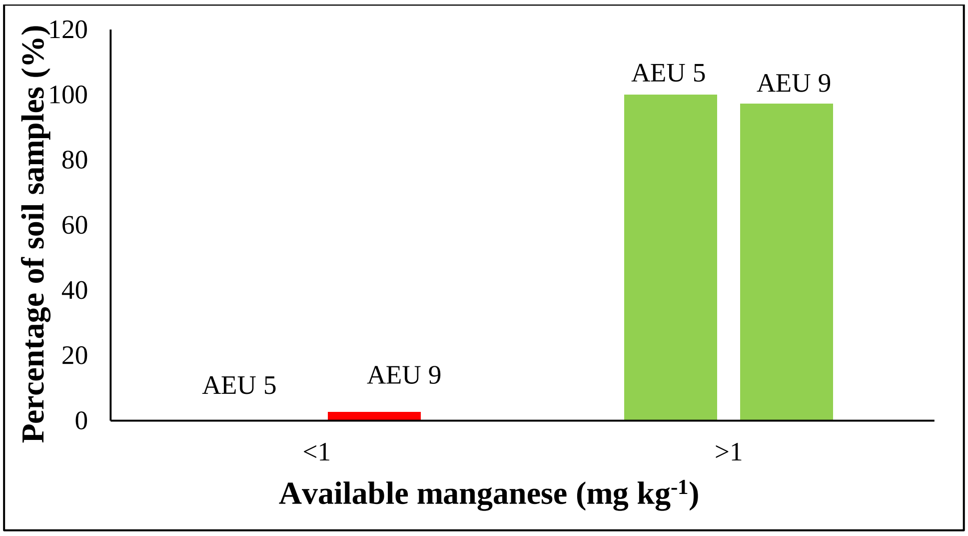

Fig.36. Percentage distribution of available manganese in the post flood soils of AEU 5 and 9 of Ernakulam district

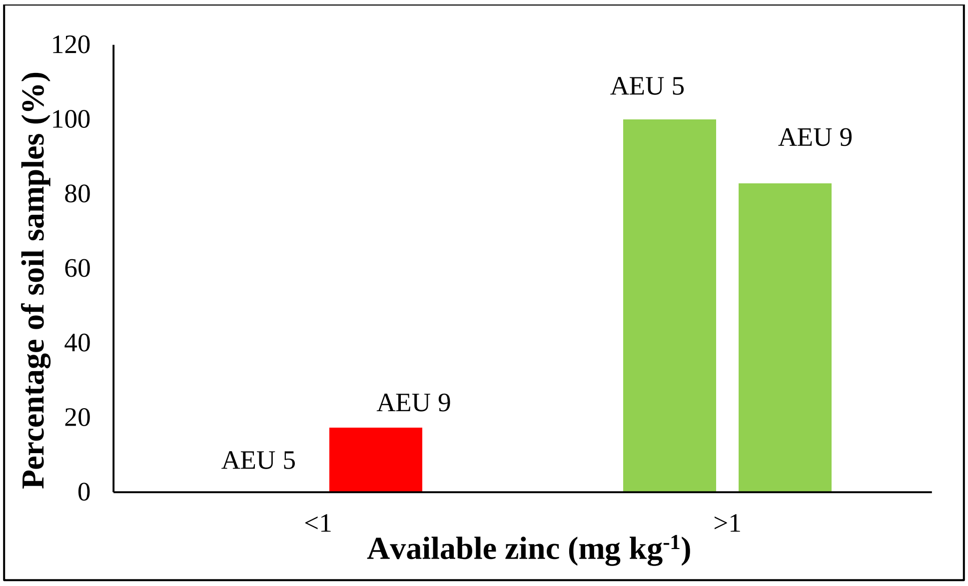

Fig.37. Percentage distribution of available zinc in the post flood soils of AEU 5 and 9 of Ernakulam district

5.2.14. Available copper

In AEU 5, 75 per cent of the samples were found deficient and 25 per cent of the samples were sufficient and many samples were found to be in below detectable range of available Cu (Fig. 38). Pre flood data showed that available Cu was in range of 0.23 to 9.42 mg kg^{-1} in *Pokkali* soils (Joseph, 2014). This deficiency is due to chelation of Cu by organic colloids (Joseph, 2014).

The available Cu content was observed deficient in 43.75 per cent of the samples and sufficient in 56.25 per cent of the samples in the post flood soils under AEU 9 (Fig. 38). Prior to flood it was sufficient in 78 per cent of the samples (GoK, 2013). This might be due to the continuous addition of organic manure and frequent application of Cu containing pesticides in the soil prior to flood (Raghunath, 2017).

5.2.15. Available boron

In the post flood soils under AEU 5 the available B content was recorded deficient in 50 per cent of the samples and sufficient in 50 per cent of the samples (Fig. 39). Prior to flood, it was recorded deficient in 64 per cent of the samples

(GoK, 2013) and it was in the range of 1.45 to 4.3 mg kg^{-1} (Joseph, 2014). In post flood soils, it ranged from 0.0003mg kg^{-1} to 1.256 mg kg^{-1}. The seawater intrusion also contributes to the high levels of B in *Pokkali* soils. Available B content in *Pokkali* soil was found high at both rice harvesting and prawn harvesting stages (Diya and Sreelatha, 2018). Santhosh (2013) also found high content of available B in organically complexed forms in lowlands of *Pokkali* tracts is mainly due to the direct marine influences along with high organic matter. The available B varied between 0.001 to 1.59 mg kg^{-1} in *Pokkali* soils (Mohan, 2016). In the post flood soils under AEU 9, all the soil samples were deficient in available B (Fig. 39). But prior to flood deficiency recorded for 65 per cent of the samples (GoK, 2013). Increased deficiency after the floods might be due to the leaching of B from the soils after heavy rainfall. Acidic condition of the soil leads to loss of B as boric acid in the soil. High P status of the soil is also one of the reason for low B.

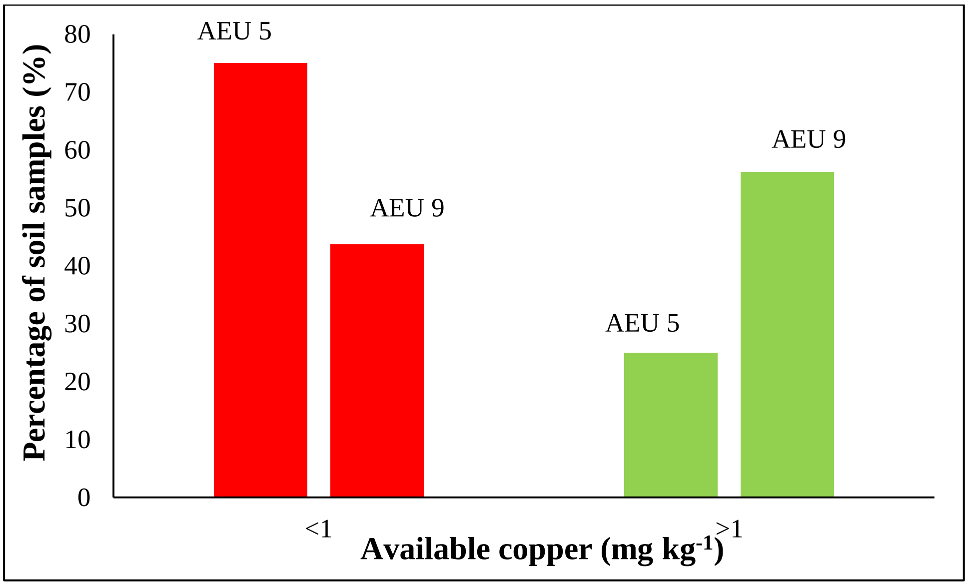

Fig.38. Percentage distribution of available copper in the post flood soils of AEU 5 and 9 of Ernakulam district

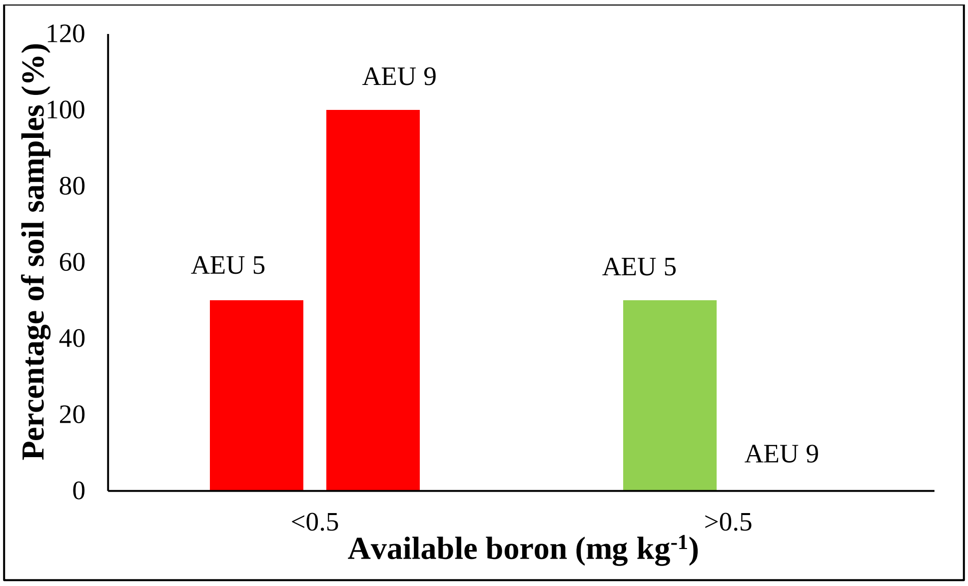

Fig.39. Percentage distribution of available boron in the post flood soils of AEU 5 and 9 of Ernakulam district

5.3. BIOLOGICAL ATTRIBUTES

5.3.1. Organic carbon

Organic carbon content was found low in 13.88 per cent of the samples, medium in 16.66 per cent of the samples and high in 69.44 per cent of the samples in post flood soils under AEU 5 (Fig. 40). Pre flood data showed that 48 per cent of the samples were in low category and 38 per cent came under medium category (GoK, 2013). Joseph (2014) reported that organic carbon was in the range of 0.26 to 3.05 per cent in *Pokkali* soils before flood while it varied from 1.07 to 4.63 per cent after flood. This increase in organic carbon content might be due to the deposition of organic debris after the floods. Krishnani *et al.* (2011) reported that during paddy culture the organic carbon content was quite higher (0.22 to 3.74%) than shrimp culture.

Pre flood soil data of organic carbon showed that 46 per cent of the samples were low and 37 per cent of the samples came under medium category (GoK, 2013). While after flood organic was found to be low in 39.06 per cent of the samples, medium in 45.31 per cent of the samples and high in 15.62 per cent of the samples in

AEU 9 (Fig. 40). This increase in organic carbon could be due to organic debris accumulation in the soil after floods. The soil samples were collected from nutmeg, banana, vegetable fields and the litter fall could also be the reason for high organic carbon in the soil (Gupta and Badanur, 1990).

5.3.2. Dehydrogenase activity and microbial biomass carbon (MBC)

The microbial biomass carbon content in AEU 5 was recorded and 16.66 per cent of the samples were below 100 µg g soil^{-1}, 55.55 per cent of the samples were in between 100 to 300 µg g soil^{-1} and 27.77 per cent of the samples were greater than 300 µg g soil^{-1} (Fig. 42). Prior to flood, microbial biomass carbon content ranged from 50.12 to 658.52 µg g soil^{-1}. In post flood soils microbial biomass carbon content ranged from 10.09 to 870.91 µg g soil^{-1}. The wide diversity and richness in microbial community in *Pokkali* soils are the cause of high dehydrogenase activity and high microbial biomass carbon. MBC was found to be decreased due to the submergence, which led to shift in aerobic to anaerobic respiration (Inglett *et al.*, 2005).

The dehydrogenase activity was found 5.55 per cent of the samples were below 75 µg TPF^{-1} g soil^{-1} 24hr^{-1}, 16.66 per cent of them were in between 75 to 150 µg TPF^{-1} g soil^{-1} 24hr^{-1}, 22.22 per cent of them were in between 150 to 225 µg TPF^{-1} g soil^{-1} 24hr^{-1} and 55.55 per cent of them were greater than 225 µg TPF^{-1} g soil^{-1}24hr^{-1} (Fig. 41). Prior to flood dehydrogenase activity in *Pokkali* soils varied from 213.22 to 9135.82 µg TPF^{-1} g soil^{-1} 24hr^{-1} (Joseph, 2014). In post flood soils dehydrogenase activity varied from 2.02 to 2090.90 µg TPF^{-1} g soil^{-1} 24hr^{-1}, 5.55 per cent of the samples were below 75 µg TPF^{-1} g soil^{-1} 24hr^{-1}, these soil samples were collected from uplands of AEU 5. Flooding the soil increases the dehydrogenase activity of the soil (Chendrayan *et al.*, 1980). The high dehydrogenase activity was seen in the areas having high organic carbon, nutrient status and litter accumulation. Soil dehydrogenase activity increases under anaerobic conditions. Innumerable varieties of microorganisms are found in *Pokkali* soils. The tidal influx also helps in the growth of beneficial microorganisms. Chandrika (1996) reported that specific, non-pathogenic, pigmental species of *Bacillus* were found in *Pokkali* soils. The presence of marine fungi and its degradation makes coastal paddy fields more fertile

(Nambiar and Raveendran, 2009). The high tide and low tide occurring twice a day maintains the fertility and productivity of *Pokkali* soils. This tidal action is helpful for the growth of beneficial microorganisms (Ranga, 2006).

The microbial biomass carbon content in AEU 9 showed that 10.93 per cent of the samples were below 100 µg g soil^{-1}, 82.81 per cent of them were in between 100 to 300 µg g soil^{-1} and 6.25 per cent of the samples were greater than 300 µg g soil^{-1} (Fig. 42) Percentage distribution of dehydrogenase activity showed that, 95.31 per cent of the samples were below 75 µg TPF^{-1} g soil^{-1} 24hr^{-1} and 4.68 per cent of them were in between 75 to 150 µg TPF^{-1} g soil^{-1} 24hr^{-1} (Fig. 41). Dehydrogenase activity increases with submerged or anaerobic conditions, aerobic condition of AEU 9 might be the reason for low dehydrogenase activity in the soil. Fungus and bacterial population is the main criteria for the microbial biomass carbon. The areas having high organic matter, litter accumulation, favourable soil moisture and anaerobic condition is conducive for microorganisms to grow (Kennedy *et al.*, 2005).

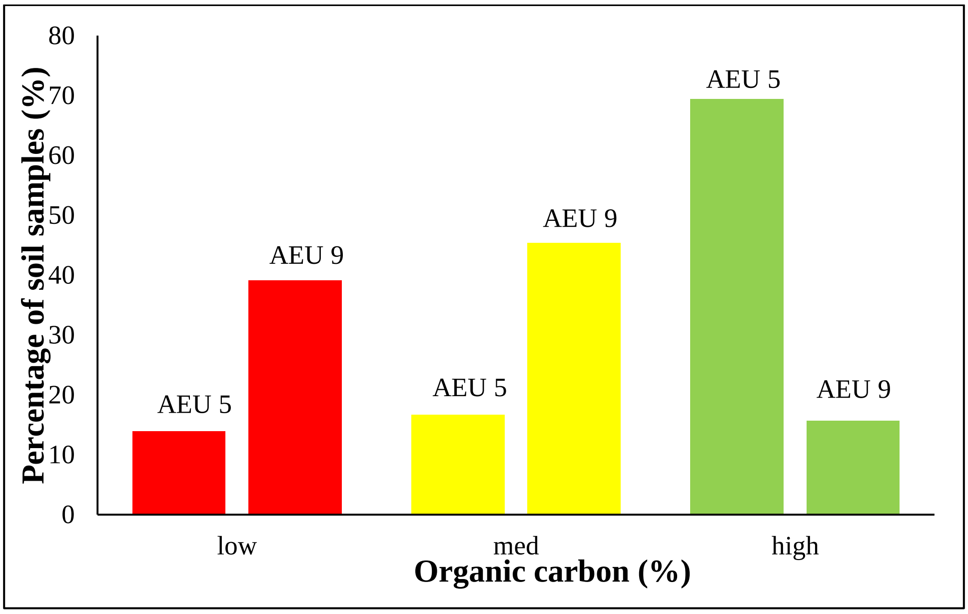

Fig.40. Percentage distribution of organic carbon in the post flood soils of AEU 5 and 9 of Ernakulam district

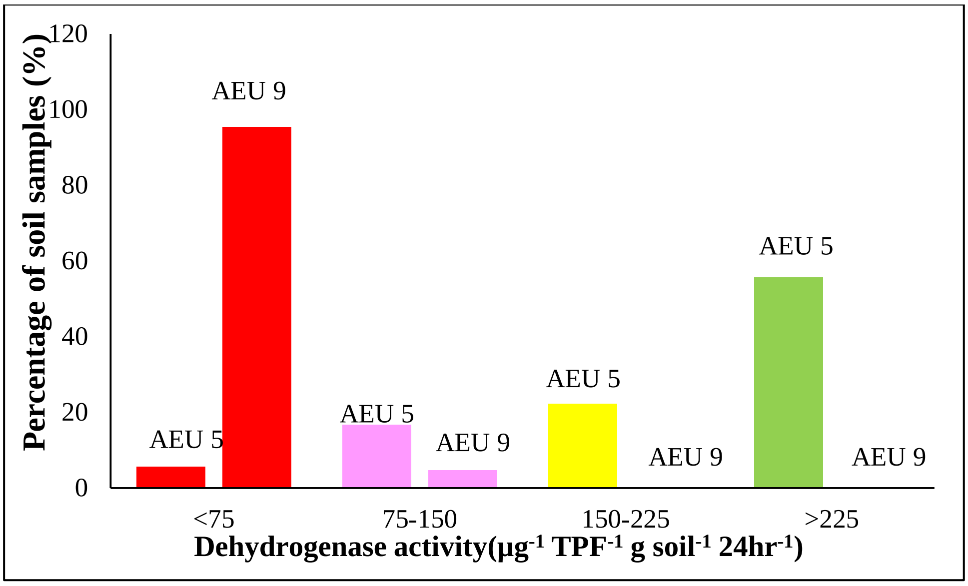

Fig.41. Percentage distribution of dehydrogenase activity in the post flood soils of AEU 5 and 9 of Ernakulam district

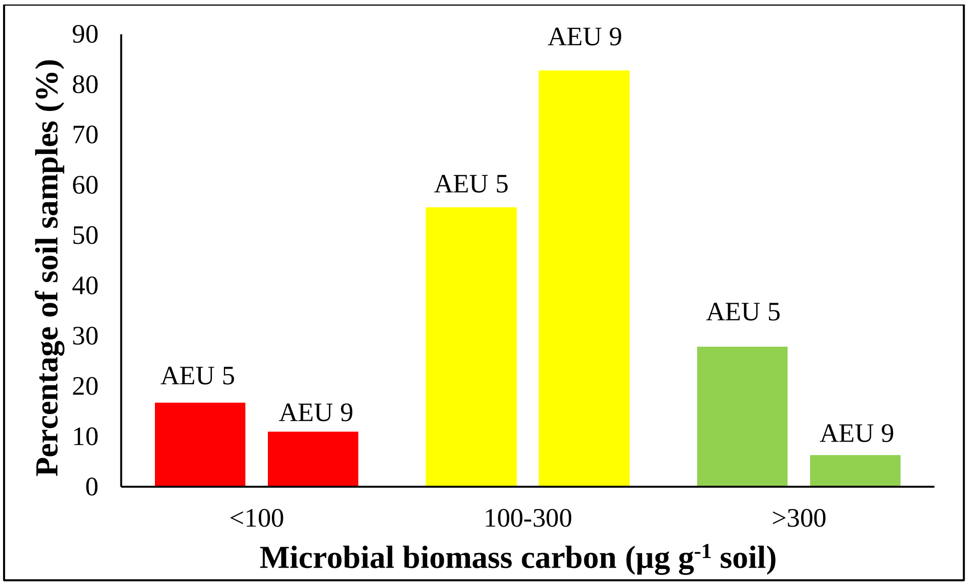

Fig.42. Percentage distribution of microbial biomass carbon in the post flood soils of AEU 5 and 9 of Ernakulam district

5.4. SOIL QUALITY INDEX

The soil quality index was recorded high in Chendamangalam panchayat (0.70) and lowest in Nayarambalam panchayat (0.47) in post flood soils of AEU 5 (Fig. 43). In AEU 9, Karumaloor panchayat recorded lowest soil quality index (0.55) and highest was observed in Sreemoolanagaram (0.79) (Fig. 44). A study on land use impact on soil quality in eastern Himalayan region of India revealed that, SQI rating was the highest for least disturbed sites such as natural forest (0.93) and grassland (0.87) and lowest for intensively cultivated sites (0.44) (Singh *et al.,* 2014).

Organic carbon, microbial biomass carbon and porosity mainly contribute to the soil quality index in AEU 5. Major limiting factors in MDS were available Fe, Mn, pH, Mg and Cu. Low availability of Mg and Cu, toxicity of available Fe and Mn and acidic pH were noticed in *Pokkali* soils. Similar to the current study, Sreelatha and Joseph (2019) also observed the deficiency of available Mg and Cu and toxicity of Mn in *Pokkali* soils under different land use systems. Shylaraj *et al.* (2013) also reported that, available Fe content of 171 to 2321 mg kg^{-1} in *Pokkali* soils. Sasidharan (2004) revealed that low soil pH in *Pokkali* soil is due to the tidal action.

In AEU 9, available Ca, S, microbial biomass carbon, N, Zn and soil moisture drive the soil quality index and major limiting factors in MDS were available Fe, B and bulk density. Bulk density was observed high in the soils, which negatively affects the plant growth. Boron was observed very low, even below detectable range and higher levels of Fe were noticed in AEU 9.

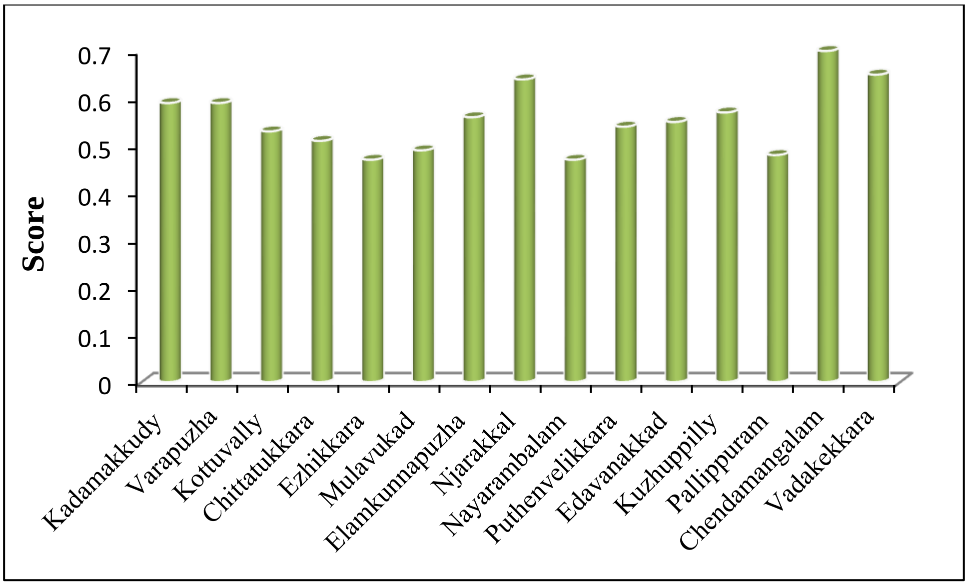

Fig.43. Soil quality index of post flood soils in different panchayats under AEU 5

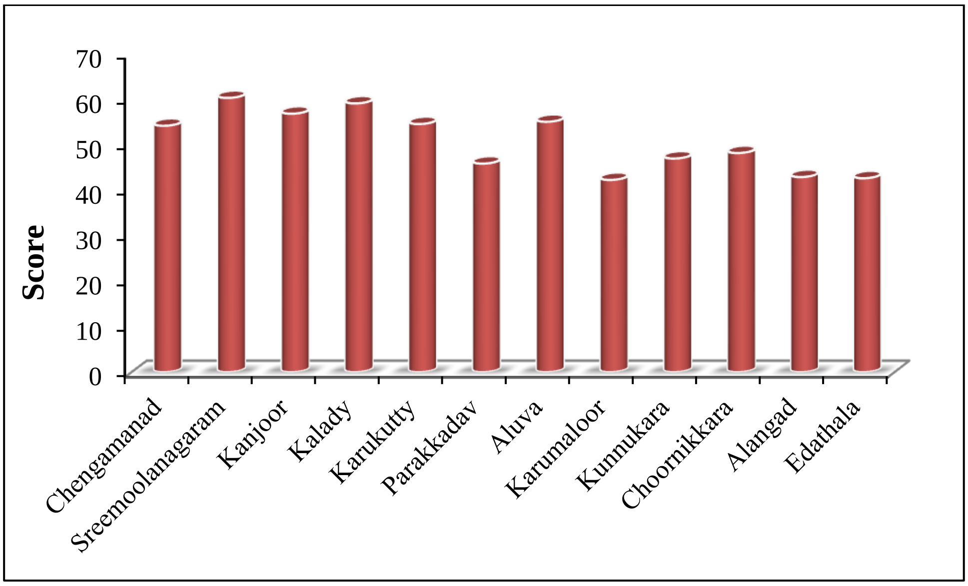

Fig.44. Soil quality index of post flood soils in different panchayats under AEU 9

The soil parameter selected from PC 1 had more weightage and contributes more to soil quality. In AEU 5, available Mg was selected from PC 1 and in AEU 9 available Ca was selected from PC 1. The order of contribution of soil attributes to soil quality index in AEU 5 was available Mg> available Fe=pH> porosity> available Mn> organic carbon> microbial biomass carbon> available Cu. The order of contribution of soil attributes to soil quality index in AEU 9 was available Ca> available S= available Fe> bulk density> available N=soil moisture> available Zn> microbial biomass carbon> available B.

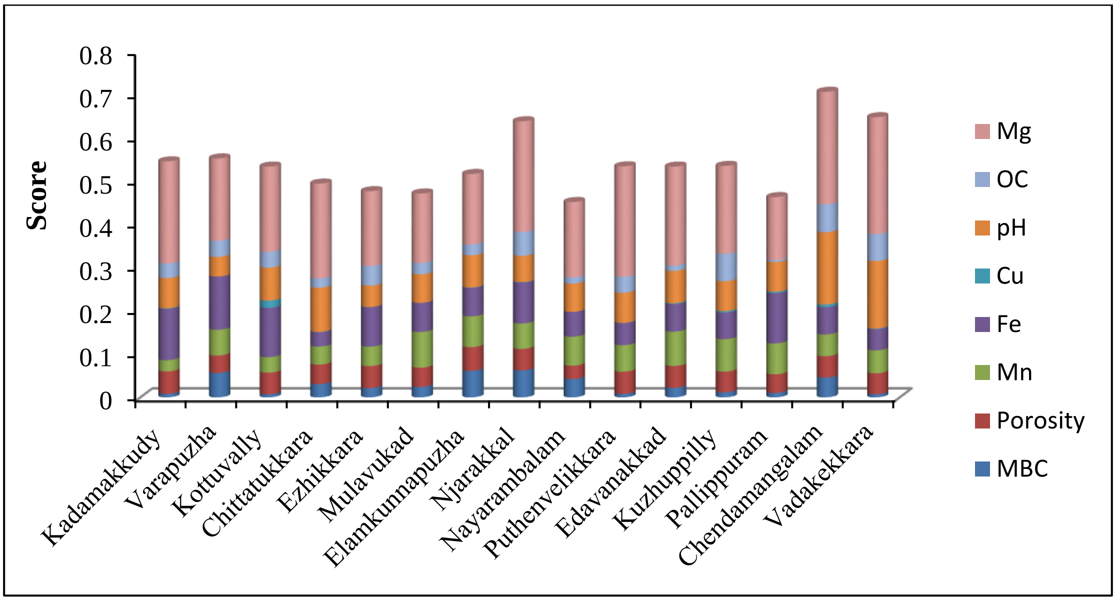

Fig.45. Contribution of each soil attributes in MDS towards SQI of AEU 5

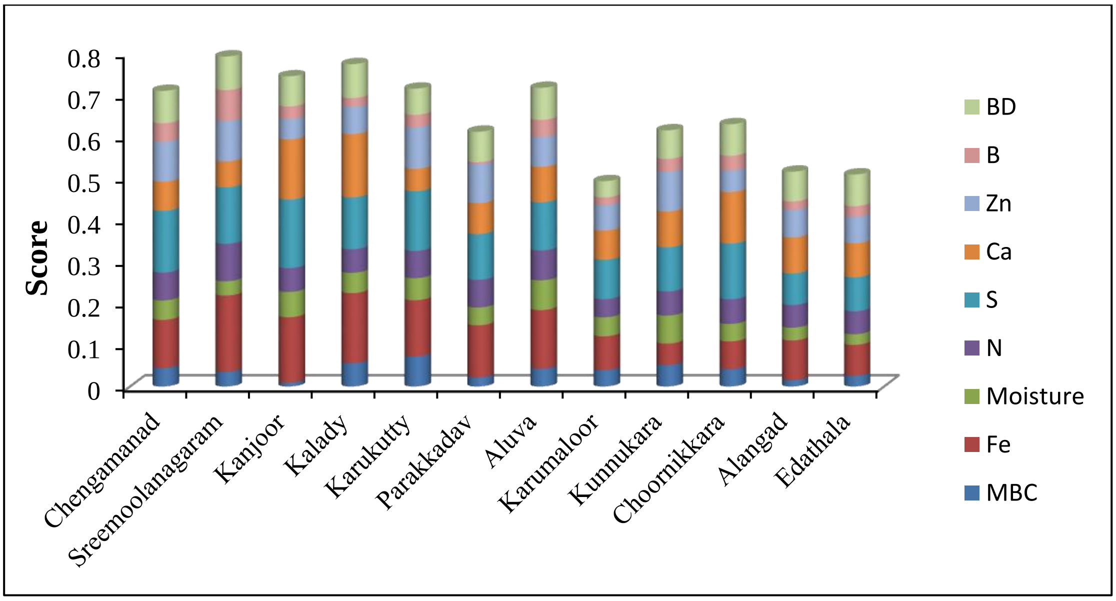

Fig.46. Contribution of each soil attributes in MDS towards SQI of AEU 9

5.5. RELATIVE SOIL QUALITY INDEX

The calculated relative soil quality index values helps in categorisation of soil to poor, medium and low in soil quality. RSQI values <50 per cent is categorized as poor, 50-70 per cent as medium and >70 per cent is categorized as good. Under AEU 5, Njarakkal, Varapuzha, Kadamakkudy, Vadakkekkara and Chendamangalam panchayths were rated as medium in soil quality and Kottuvally, Chittatukkara, Ezhikkara, Mulavukad, Elamkunnapuzha, Nayarambalam, Puthenvelikkara, Edavanakkad, Kuzhuppilly and Pallippuram comes under poor soil quality. No panchayat came under high category (Fig. 47).

The results of the present study showed that Kottuvally, Elamkunnapuzha, Nayarambalam and Kuzhuppilly panchayats were poor in relative soil quality index. This might be due to the influence of MDS indicators. Post flood assessment revealed that, MDS consisted of low available Mg and Cu, toxicity of available Fe and Mn and acidic pH in these panchayats. This was different from the result obtained by Sreelatha and Joseph (2019). According to their pre flood data, medium soil quality index was recorded for these panchayats (Table 33). This shift in soil quality in these panchayats shows the change in indicators selected for minimum data set. MDS indicators for the pre flood soils was available water, bulk density, organic carbon, pH, available S, Mn, Mg, base saturation, fine sand per cent, MBC, EC, aggregate stability and silt per cent while it has changed in the post flood assessment. Even slight change in nutrient level of MDS indicators greatly affects the soil quality index.

Table 35. Comparison of RSQI with pre flood data

Panchayats	Relative soil quality index % (2013-14) Sreelatha and Joseph (2019)	Relative soil quality index % (2018-19)
Kuzhuppilly	69.4	47.05
Nayaramabalam	72.5	40.5
Elamkunnapuzha	58.4	48.2
Kottuvally	62.7	45.6

Under AEU 9, Chengamanad, Sreemoolanagaram, Kanjoor, Kalady, Aluva, and Karukutty panchayats was rated as low category and Alangad, Edathala, Parakkadav, Karumaloor, Kunnukara and Choornikkara panchayats comes under medium category. No panchayat had shown RSQI rated as high (Fig. 48). This might be due to the influence of MDS indicators.

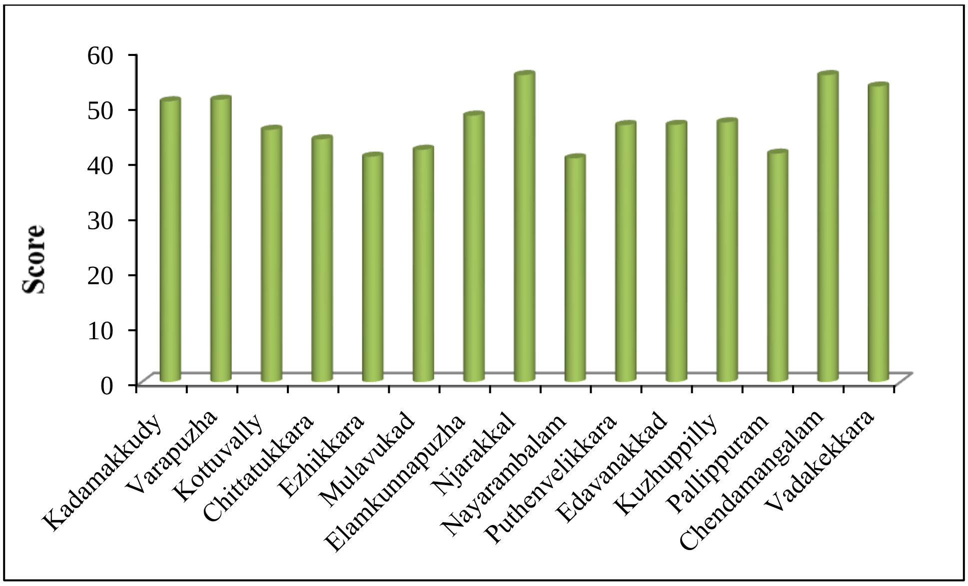

Fig.47. Relative soil quality indices of different panchayats under AEU 5

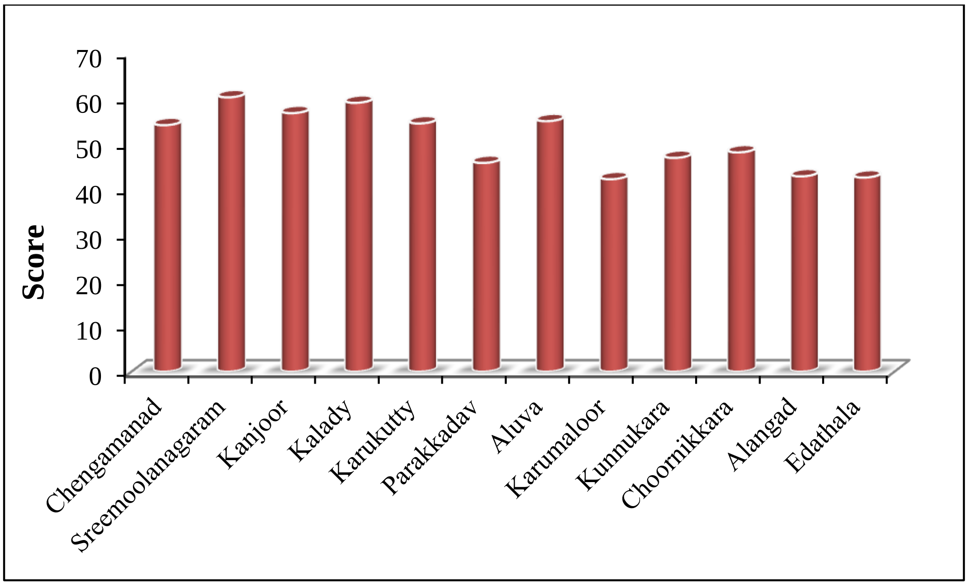

Fig.48. Relative soil quality indices of different panchayats under AEU 9

Summary

SUMMARY

The present study entitled 'Assessment of soil quality in the post flood scenario of AEU 5 and AEU 9 of Ernakulam District of Kerala and mapping using GIS techniques' was conducted with the objective to evaluate soil quality of the soils after the flood in the areas severely affected by flood and to develop geo-referenced database and maps using GIS techniques. For this purpose, 100 composite soil samples were collected from different panchayats of AEU 5 and AEU 9 of Ernakulam district. Soils were analysed for their physical attributes (bulk density, particle density, porosity, water holding capacity and soil moisture content), chemical attributes (pH, EC, exchangeable acidity, effective cation exchange capacity, available N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B) and biological attributes (organic carbon, dehydrogenase activity and microbial biomass carbon). Geo-referenced data was used for the preparation of maps by GIS techniques.

Soil quality was calculated using principal component analysis (PCA). Principal component analysis (PCA) performed for 23 soil attributes resulted in 7 PCs to develop minimum data set (MDS) containing 8 and 9 attributes for AEU 5 and 9 respectively. After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods. Three types of scoring curves were used: i) '*more is better*', ii) '*less is better*', iii) '*optimum*' curve. Soil quality index (SQI) was worked out and using relative soil quality index (RSQI) the soils were categorised as 'poor', 'medium' and 'good'. The main findings from the study are summarised below.

- Bulk density of soils in AEU 5 showed comparatively lower values (0.23 to 1.53 Mg m^{-3}) and in AEU 9 it ranged from 0.89 to 1.73 Mg m^{-3}.
- Particle density of the soils varied from 2.06 to 2.85 Mg m^{-3} in AEU 5 and 2.21 to 2.85 Mg m^{-3} in AEU 9.
- Higher soil porosity was observed in the soils of AEU 5 and in AEU 9 it was in medium range.

- Water holding capacity of the soils varied from 23.05 to 88.6 per cent in AEU 5 and 27.51 to 49.91 per cent in AEU 9.
- Soil moisture content in the soils of AEU 5 was higher and in AEU 9 it varied from 2.03 to 36.85 per cent.
- The pH of the soils varied from 3.04 to 7.22 in AEU 5 and 5.01 to 7.69 in AEU 9.
- In AEU 9, all the soil samples were non saline in nature and in AEU 5 EC varied from slightly saline to highly saline.
- Exchangeable acidity varied from 0.010 to 3.33 cmol(+)kg^{-1} in AEU 5 and 0.13 to 2.866 cmol(+)kg^{-1} in AEU 9.
- Available N was observed medium to high in AEU 5 and at medium range in AEU 9.
- Available P was recorded high in AEU 5 and 9.
- Available K was found to be high in AEU 5 and in AEU 9 it was in medium range.
- In AEU 5, effective cation exchange capacity of the post flood soils varied from 9.41 to 71.32 cmol(+)kg^{-1} and 9.24 to 18.91 cmol(+)kg^{-1} in AEU 9.
- Available Ca was sufficient in AEU 5 but in AEU 9 it varied from 96.5 to 1450.5 mg kg^{-1}.
- The available Mg was found deficient in both AEUs.
- Higher S content was observed in AEU 5 and in AEU 9 sulphur content varied from 3.73 to 36.66 mg kg^{-1}.
- The available Fe, Mn and Zn were sufficient in both AEU 5 and 9.
- Available B was deficient in AEU 5 and 9, available Cu was deficient in AEU 5 and in AEU 9 it varied from 0.06 to 262.8 mg kg^{-1}.
- Organic carbon content was medium to high in AEU 5 but in AEU 9 it is in medium range.
- Dehydrogenase activity and MBC were higher in AEU 5 but low in AEU 9.
- Nutrient index for OC, N, P, K were high in AEU 5 but in AEU 9, it was high for P, low for OC and medium for N and K.
- Soil quality index was calculated using principal component analysis (PCA).

- There are three main steps involved in the soil quality index method which includes (i) selection of MDS indicators (ii) scoring of each MDS indicators (iii) computation of index of soil quality.
- Principal component analysis resulted in 7 PCs for AEU 5 and AEU 9.
- MDS for the soil quality assessment in AEU 5 included available Mg, pH, porosity, available Mn, organic carbon, microbial biomass carbon, available Cu and Fe.
- MDS for the soil quality assessment in AEU 9 included available Ca, available S, bulk density, available N, available Zn, microbial biomass carbon, available B, available Fe, soil moisture content.
- Non-linear scoring was used with scoring functions *'more is better'*, '*less is better'* and '*optimum'* curve.
- Soil quality index was in the range of 0.42 to 0.76 in AEU 5 and 0.39 to 0.92 in AEU 9.
- The highest RSQI value was found in Aluva (69.7%) and the lowest in Edathala (29.55%) under AEU 9. In AEU 5 the highest RSQI was obtained in Vadakkekkara (71.58%) and the lowest value obtained in Nayarambalam (37.06%).
- RSQI was categorised as low to medium in both AEU 5 and 9.
- According to the pre flood data in AEU 5, medium soil quality index was recorded for Kottuvally, Elamkunnapuzha, Nayarambalam and Kuzhuppilly panchayats but post flood assessment revealed that they have shifted to poor soil quality.
- This might be due to the influence of MDS indicators.
- Prepared geo referenced maps with respect to spatial distribution of important physico-chemical, biological properties and RSQI.

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Appendix I: Soil fertility ratings

a. Organic carbon and primary nutrients

Ratings	Organic carbon (%)	Available nutrients		
		N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Low	<0.75	< 280	< 10	< 116
Medium	0.75- 1.5	280 - 560	10 – 24	116 – 275
High	>1.5	> 560	> 24	> 275

b. Secondary nutrients

Nutrient	Category	
	Deficiency	Sufficiency
Available calcium (mg kg^{-1})	< 300	>300
Available magnesium (mg kg^{-1})	< 120	>120
Available sulphur (mg kg^{-1})	< 5	>5

c. Micronutrients

Nutrient (mg kg^{-1})	Category	
	Deficiency	Sufficiency
Available iron	< 5	> 5
Available manganese	< 1	> 1
Available zinc	< 1	> 1
Available copper	< 1	> 1
Available boron	< 0.5	> 0.5

(KAU, 2016)

d. Ratings for RSQI

RSQI (%)	Rating
< 50	Low
50 - 70	Medium
> 70	High

(Karlen and Scott, 1994)

e. Nutrient index ratings for organic carbon, available nitrogen, phosphorus and potassium

Nutrient Index	Rating
< 1.67	Low
1.67 – 2.33	Medium
> 2.33	High

(Ravikumar and Somashekar, 2013)

Appendix II. a. Correlation analysis of post flood soils from AEU 5 of Ernakulam district

	DHA	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	pH	EC	Ex. A	OC	Ecec	BD	PD	Poro.	WHC	Moist	MBC
DHA	1	0.177	0.289	0.23	.572**	.574**	0.357	.457*	.459*	.564**	-0.141	.612**	.521**	-0.128	-0.31	0.314*	.521**	-0.294	-0.158	0.246	.584**	.474*	-0.056
N		1	.648**	-0.093	.676**	.710**	.716**	-0.376	0.253	0.345	-0.124	0.24	-.544**	0.208	0.304	0.568*	.711**	-0.329	-.521**	0.158	.690**	.740**	0.187
P			1	-0.139	.786**	.593**	.743**	-0.222	0.194	.414*	-0.108	0.18	-0.222	-0.059	-0.011	0.307*	.543**	-0.3	-0.324	0.206	.532**	.539**	0.091
K				1	0.088	0.375*	-0.162	0.329	-0.226	-0.154	-0.093	0.29	0.391	-0.315	-.428*	0.114	0.385	-0.249	0.109	0.246	0.386	0.355	0.001
Ca					1	.857**	.820**	-0.154	0.253	.488*	-0.058	.500*	-0.129	0.042	0.025	0.158	.838**	-.527**	-.418*	.405*	.851**	.791**	0.217
Mg						1	.766**	-0.018	0.305	.482*	-0.021	.576**	-0.074	0.057	-0.176	0.265	.969**	-.539**	-.472*	0.393	.905**	.960**	0.233
S							1	-0.314	0.283	.421*	0.005	0.332	-0.356	0.219	0.124	0.157	.702**	-.441*	-0.363	0.346	.644**	.748**	0.311
Fe								1	0.06	0.043	0.107	0.382	.545**	0.022	-0.366	0.206	0.002	0.14	0.055	-0.123	-0.013	-0.057	-0.189
Mn									1	.752**	0.052	0.301	-0.022	-0.029	0.04	0.218	0.211	-0.358	-0.321	0.305	0.202	0.277	-0.277
Zn										1	-0.091	.557**	0.01	0.111	-0.185	0.386	.429*	-0.31	-0.341	0.203	0.35	.437*	0.088
Cu											1	0.033	-0.061	.426*	-0.073	-0.041	-0.045	-0.073	0.069	0.214	-0.077	0	-0.229
B												1	0.032	0.159	-0.181	0.33	.573**	-0.345	-0.14	0.298	.490*	.562**	0.236
pH													1	-0.318	-.605**	-0.076	-0.112	0.133	0.241	-0.056	-0.04	-0.214	-0.208
EC														1	0.304	.411*	0.066	0.038	-0.155	-0.052	0.066	0.107	0.158
Ex. Acidity															1	0.172	-0.106	-0.18	-0.198	0.126	0.007	-0.072	-0.162
OC																1	0.292	-0.381*	-0.364*	0.244*	0.271*	0.316	0.425**
ECEC																	1	-.545**	-.566**	0.36	.916**	.952**	0.242
BD																		1	0.266	-.940**	-.626**	-.622**	-0.092
PD																			1	0.049	-.481*	-.547**	0.192
Poro																				1	.471*	.446*	0.091
WHC																					1	.890**	0.135
Moist																						1	0.233
MBC																							1

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

b. Correlation analysis of post flood soils from AEU 9 of Ernakulam district

	DHA	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	pH	EC	EA	OC	Ecec	BD	PD	Poro.	WHC	Mois.	MBC
DHA	1	-0.045	-0.067	0.065	0.149	0.118	0.08	0.206	.396**	0.083	-0.012	-0.064	-0.09	0.114	-0.174	0.523*	0.186	0.129	.301**	-0.004	0.074	-0.143	0.105
N		1	-0.202	0.149	-0.026	0.171	0.156	0.106	.296**	-0.056	-0.019	.344**	-0.11	-0.073	.239*	0.403*	0.124	-0.152	-.259*	0.049	0.217	.310**	0.059
P			1	-0.001	-0.181	-0.152	-0.192	-0.079	-0.154	0.006	-0.051	-0.036	-0.148	0.049	0.01	-0.024	-.242*	0.128	-0.099	-0.157	-.322**	-0.129	-0.167
K				1	0.046	.267*	.315**	0.179	0.205	-0.166	-0.067	0.02	0.129	-0.221	0.067	0.14	0.176	-0.104	-0.147	0.049	.253*	0.138	-0.104
Ca					1	.464**	-0.191	-0.089	0.159	.421**	0.113	-0.083	.631**	0.095	-.308**	-0.072	.802**	-0.105	0.048	0.118	0.145	0.052	-0.078
Mg						1	-0.077	0.024	.302**	0.091	-0.014	0.095	.338**	0.079	-.393**	-0.011	.497**	0.087	0.031	-0.061	.269*	0.207	0.048
S							1	.516**	.363**	-0.057	-0.091	-0.095	-0.088	-0.102	.370**	.316**	-0.01	-.290*	0.179	.328**	.506**	-0.004	-0.033
Fe								1	.281*	0.128	0.066	-0.152	-0.217	-0.139	0.182	.304**	0.046	-.277*	0.223	.334**	.233*	0.044	-0.181
Mn									1	0.091	0.13	-0.098	-0.035	-0.068	0.045	0.143	.385**	-0.078	.236*	0.161	.366**	.235*	0.131
Zn										1	.589**	-0.151	.231*	0.194	-0.221	-0.084	.361**	-0.08	0.17	0.137	-0.102	-.254*	-0.153
Cu											1	-0.065	-0.016	0.06	-0.085	-0.005	0.22	0.003	0.166	0.058	-0.129	-0.059	-0.051
B												1	0.028	0.088	-0.053	-0.043	-0.023	0.025	-.307**	-0.146	0.203	0.008	-0.002
pH													1	-0.104	-.274*	-0.107	.468**	-0.086	0.024	0.084	0.151	0.025	-0.023
EC														1	-0.08	-0.027	0.078	0.153	0.002	-0.139	-0.048	-0.137	-0.181
EA															1	0.096	-0.06	-.289*	-0.041	.246*	0.124	0.084	0.019
OC																1	0.037	-0.319*	-0.122*	0.124**	0.147*	-0.102	0.444*
Ecec																	1	-0.212	-0.006	0.195	.301**	.306**	-0.025
BD																		1	0.027	-.927**	-.292*	-.363**	0.113
PD																			1	.344**	0.066	-.352**	0.118
Poro																				1	.291*	0.218	-0.058
WHC																					1	.262*	0.08
Moist.																						1	0.107
MBC																							1

**. Correlation is significant at the 0.01 level (2-tailed)

*. Correlation is significant at the 0.05 level (2-tailed)

ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF AEU 5 AND AEU 9 OF ERNAKULAM DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Kerala state witnessed large scale devastating flood in 2018 due to excess rainfall, causing significant damage to agricultural sector and human life. One of the most affected districts was Ernakulam, especially AEU 5 and AEU 9. The AEU 5 - *Pokkali* lands, represent the lowlands, often below sea level, in coastal areas of Ernakulam district and extending to parts of Thrissur and Alappuzha districts. The soils are hydromorphic, often underlain by potential acid-sulphate sediments with unique hydrological conditions. Seawater inundation is not controlled and hence soils are acid-saline. The AEU 9 - south central laterites represent midland laterite terrain with typical laterite soils.

The study aimed at the assessment of soil quality in the post flood scenario of AEU 5 and AEU 9 in Ernakulam district and to develop maps on soil characters and quality using GIS techniques and to workout soil quality index (SQI). For this purpose 100 geo-referenced soil samples were collected from different panchayats of AEU 5 and AEU 9 in Ernakulam district and were characterized for physical, chemical and biological properties.

The *Pokkali* soils recorded low bulk density whereas porosity, water holding capacity and soil moisture were found high. Available N content was medium to high, available phosphorus and potassium was high in the soil. Among the secondary nutrients, available Ca and S were found sufficient for majority of the samples, while a deficiency of available Mg was noticed in *Pokkali* soils.

In AEU 9, the soil pH varied from 5.01 to 7.69 and all the soils had an electrical conductivity less than 1.0 dS m^{-1}. Organic carbon was noticed low to medium in the soils. Available N content was medium for 87 per cent of the samples, whereas all the samples were high in available P content. Available K was recorded low to medium values in AEU 9.

Soil quality index was calculated using principal component analysis (PCA). There are three main steps involved in the soil quality index method which includes

(i) selection of a minimum data set (MDS) of indicators (ii) formation of the MDS indicators and scoring of each indicators (iii) computation of index of soil quality. For developing minimum data set, principal component analysis (PCA) was performed for 23 soil attributes and resulted in 7 PCs. The indicators with high loading factors in each PCs were selected to develop minimum data set (MDS). MDS constituted 8 attributes for AEU 5 and 9 attributes for AEU 9 respectively. After the development of MDS, the soil indicators were converted to unit-less scores ranging from 0 to 1 using non-linear scoring function methods. Three types of scoring curves were used: i) *more is better*, ii) *less is better*, iii) *optimum curve*.

Soil quality index ranged from 0.42 in Nayarambalam to 0.76 in Vadakkekkara in AEU 5, and 0.39 in Edathala to 0.92 in Aluva in AEU 9. The highest RSQI value was recorded in Aluva (69.7%) and the lowest in Edathala (29.55%) under AEU 9. In AEU 5 the highest RSQI was obtained in Vadakkekkara (71.58%) and the lowest in Nayarambalam (37.06%). Nutrient indices of flood affected areas in AEU 9 were low with respect to organic carbon and available potassium, medium with respect to available nitrogen and high with respect to available phosphorus. Nutrient index was high for nitrogen, phosphorus, potassium and organic carbon in AEU 5. Significant positive correlations were observed between organic carbon and available nitrogen, organic carbon and soil moisture content. Negative correlation existed between bulk density and porosity, organic carbon and bulk density in both AEUs.

The present study revealed that soil fertility and productivity have been disturbed after the floods. In AEU 9 available potassium was found decreased after the flood. Prior to flood Kottuvally, Elamkunnapuzha, Edavanakkad and Kuzhuppilly panchayats in AEU 5 were medium in relative soil quality index (Joseph, 2014) and post flood assessment showed that these panchayats shifted to poor relative soil quality index.