ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 14 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

SREEJITHA M BABU

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THESIS

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VELLAYANI, THIRUVANANTHAPURAM – 695 522

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DECLARATION

I hereby declare that this thesis entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 14 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani **Sreejitha M Babu**

Date: (2018-11-044)

CERTIFICATE

Certified that this thesis, entitled **"ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 14 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** is a record of research work done independently by **Ms. Sreejitha M Babu** (2018-11-044) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Vellayani

Date:

Dr. Naveen Leno
(Major Advisor, Advisory Committee)
Assistant Professor (Soil Science and Agricultural Chemistry)
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Sreejitha M Babu** (2018-11-044), a candidate for the 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 14 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS"** may be submitted by **Ms. Sreejitha M Babu** (2018-11-044),in partial fulfilment of the requirements for the degree.

Dr. Naveen Leno
(Chairman, Advisory Committee)
Assistant Professor
Department of Soil Science
and Agricultural Chemistry
College of Agriculture, Vellayani

Dr. K. C. Manorama Thampatti
(Member, Advisory Committee)
Professor and Head
Department of Soil Science
and Agricultural Chemistry
College of Agriculture, Vellayani

Dr. G. Byju
(Member, Advisory Committee)
Principal Scientist
Soil Science
ICAR-Central Tuber
Crops Research Institute
Sreekariyam, Thiruvananthapuram

Dr. R. Gladis
(Member, Advisory Committee)
Assistant Professor
Department of Soil Science
and Agricultural Chemistry
College of Agriculture, Vellayani

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Introduction

1. INTRODUCTION

Agriculture being reliant to a large extent on weather, climate, land and water for its ability to sustain, is particularly vulnerable to natural disasters. The risk of flooding globally accounts for about a third of all losses due to natural hazards. Floods caused a 20 percent of the cumulative production loss in crops amounting to 19.5 billion USD between 2005 and 2015 in developing countries (Conforti *et al*., 2018). Flood is one of the most destructive and devastating perpetual natural disasters in India (Ameen *et al*., 2019) caused mainly during the monsoon season by irregular distribution and high intensity precipitation. The damage caused by flood depends mainly on the duration and intensity of the rainfall, the type of soil, the slope, and the land use. In recent times, the heavy precipitation and consequent opening of dam floodgates in August 2018 resulted in severe flooding in many parts of Kerala which had seriously affected a large human population and their resources. The three-day intense rainfall that occurred in Kerala on 15, 16 and 17 August 2018 led to severe flooding in the state (Sudheer *et al*., 2019). The heavy rainfall, which was more than 164 per cent than the normal caused the dams to be filled to maximum capacity, causing all barriers to be opened. It costed 483 lives and affected 1/6th of the total population. A total of 57,000 hectares of agriculture crops were destroyed (Santhi and Veerakumaran, 2019).

The dynamics of the soil nutrients in a region affected by floods can be highly complex and variable. Soil nutrients dissolve in floodwaters during flooding and are transferred from floodplain surfaces in to neighbouring rivers, and soil nutrients can also be transferred by lateral flow from the river to floodplains. A sequence of physical, chemical, and biological processes is set in motion by flooding or submergence of an air-dry soil in to water. Flooding can lead to both increase and decrease in soil nutrient content that profoundly influence the soil quality of that region. Soil quality is defined as ‘the ability of a soil to work within natural or controlled ecosystem boundaries, to uphold the productivity of plants and animals, hold water and air quality, and encourage human health and habitat (Karlen *et al.,* 1997). The significance of soil quality is in achieving sustainable system of land use and management, balancing productivity and conservation of environment, which is a matter of prime concern.

The spatial and temporal variability in the soil physicochemical and biological fabric inflicted by the floods has to be systematically studied, classified, correlated and interpreted for evolving future management strategies. Earlier, traditional methods of soil survey were employed to collect data on soil resource analysis. Although the data obtained through these methods is reliable and precise, it does not help to create the layers of spatial variability of soil properties. In recent years, the rapid development of agri informatics and spatial technologies offer advanced tools and techniques in agriculture for soil resource inventories. The development of Geographic Information System (GIS), Global Positioning System (GPS) and Remote Sensing (RS) technologies in particular has allowed data collection and analysis to establish field maps in all possible ways, as well as evaluating complex spatial relationships between soil fertility factors.

Idukki district of Kerala with 12 rivers, harbours the Idukki arch dam and the Cheruthoni and Kulamavu dams with a reservoir capacity of over 2 billion tons of water. During the unprecedented floods of 2018, Idukki district was among the most seriously affected in Kerala. Floods and landslides displaced large quantities of surface soil particularly from slopy lands and deposited them at different locations. In this context, many paddy fields were affected by silt deposits. Based on the climate, geomorphology, land use and soil variability, 48.06 per cent of Idukki district is classified under Southern High Hills (AEU 14). Rajakkad, Vazhathope, Kanjikuzhy, Mariyapuram, Konnathadi and Kamakshi are the panchayats in AEU 14 that underwent extensive flooding which created both run off and deposits of debris and sediments in many places. Deposit scale may be graded from mild to extreme. The variety of sedimentary deposits that were brought in are liable to alter the physicochemical and biological soil characteristics of the soil. The rectification of the soil problems has to be scientifically addressed integrating traditional scientific methodology of surveying, sampling, analysing, correlating and interpreting the generated soil information with modern techniques of geoinformatics and spatial mapping with a view to formulate climate resilient soil management strategies and interventions.

Hence the present study on ‘Assessment of soil quality in the post-flood scenario of AEU 14 in Idukki district of Kerala and generation of GIS maps’ was carried out with the following objectives.

1. To assess the soil quality of post-flood soils of severely affected villages in Idukki, Adimali and Nedumkandam blocks of AEU 14 in Idukki district
2. To develop maps on soil characters and quality using GIS techniques
3. To workout soil quality index (SQI).

Review of Literature

2. REVIEW OF LITERATURE

The present study is an attempt to study the effect of flooding on the soil quality in post-flood soils of AEU 14 of Idukki district of Kerala. The literature pertaining to the present study "Assessment of soil quality in the post-flood scenario of AEU 14 in Idukki district of Kerala and generation of GIS maps" is reviewed under the following heads:

2.1. Floods

2.2. The 2018 Kerala flood

2.3. Flood and soil quality

2.4. Soil health and sustainability

2.5. Soil Quality: Concept and Assessment

2.6. Geographic information system (GIS) and soil mapping

2.1. FLOODS

Flooding is a temporary situation, in which sudden water is deposited by rapid runoff by rain or from inland or tidal, causing complete inundation (Jeb and Aggarwal, 2008).

River inundations are expected to affect 21 million people worldwide every year and are predicted to increase to 54 million by 2030. In the 27-year period 1975-2001, 1,75,000 people were killed and 2.2 billion worldwide affected (Salvati *et al.*, 2018).

Floods are the most widespread natural disasters impacting people, their life and environment. Floods are among the most frequent and damaging natural disasters that threaten human lives and inflict significant economic damage worldwide. The majority of the floods occur in the monsoon season and are often connected to tropical storms. In the majority of Indian water basins, floods are due to these factors (Ameen *et al.*, 2019).

2.1.1. Floods and the Indian Scenario

India has seen some of the most devastating incidents of heavy precipitation in recent past causing flooding and loss of life. Heavy precipitation in Mumbai caused more than 1000 people to die in 2005 (Kumar *et al*., 2008).

In 2013, excessive rainfall occurred in Uttarakhand, which resulted in major flooding and cost the lives of about 6000 people and severe economic losses (Kumar, 2013).

Among the weather-related disasters that occurred between 1995 and 2015, 47 per cent were due to flooding and this affected about 2.3 billion people from Asia (Wahlstrom and Guha-Sapir, 2015).

The heavy precipitation incident in 2015 triggered flooding in Chennai which resulted in the damage of about $3 billion (Oldenborgh *et al.*, 2016).

Extreme rainfall and floods have been one of the costliest natural disasters in India and other parts of the world. Bangladesh is the country most affected by floods and then comes India and one out of five global death rates is due to flooding. In India, 23 states are prone to floods and about 40 Mha of land are liable to floods. India accounts for approximately one-fifth of the world's death rate due to floods. About one-eighth of India's topographical area is flood-prone (Joy *et al.*, 2019).

2.2. THE 2018 KERALA FLOOD

Kerala experienced an extremely high rainfall from 1 June 2018 to 19 August 2018 which resulted in severe flooding in 13 districts of Kerala. In this devastating flood, only one district was left out (Sankar, 2018).

According to IMD data, 2346.6 mm rainfall was received against the expected 1649.5 mm from 1 June 2018 to 19 August 2018 in Kerala. The received rainfall was 42 per cent higher than expected. Kerala experienced 15 per cent more than the average rainfall in June, 18 per cent more in July and August, and 164 per cent more from 1 August to 19 August. The heavy rainfall started on 14 August and ended on 19 August, resulting in a flood that affected 13 out of 14 districts (Joy *et al*., 2019).

Idukki, Ernakulam, Kollam, Kottayam, Pathanamthitta, Malappuram and Wayanad were the districts most severely affected in Kerala during the 2018 flood. Excessive rainfall (>60 % more than normal) in the district of Idukki and high rainfall (between 20 % and 56 % more than normal) in the districts of Ernakulam, Kollam, Kottayam, Malappuram, Pathanamthitta and Palakkad, was recorded in Kerala during the 2018 monsoon season (Lal *et al*., 2020).

Idukki recorded the highest rainfall among the different districts of the state, which was almost 100 per cent in excess compared to the average rainfall (3555 mm over the average 1852 mm). Peerumedu (>800 mm) and Idukki (>700 mm) of Idukki district were the two rain gauge stations that received maximum cumulative rainfall during 15–17 August 2018 (Sudheer *et al*., 2019).

2.2.1. Impact of Kerala Floods on Agriculture

A team of 28 scientists and technical staff of the ICAR-CTCRI undertook a field survey of all major flood affected areas in Kerala. The study results showed that the state lost tuber crops in a total area of 7679.30 hectares with a gross economic loss of approximately ₹288.04 crores. This loss accounts for 8.65 per cent of the total tuber crop area, which is 88803 ha. Studies with ecological niche and crop models foresee a cumulative tuber crop yield loss of 15 per cent in 2018 due to flooding and its aftermath. The state lost 5838.71 hectares of cassava, causing the farmers to lose some ₹204.35 crores. The worst affected districts were Alappuzha, Malappuram, Ernakulam, Thrissur and Pathanamthitta, with a 76.46 per cent fall in area under tuber crops cultivation (ICAR-CTCRI, 2018).

The agricultural sector was adversely affected by the heavy rainfall and flood. Food crop production mainly rice exhibited a deep decline as the paddy fields were flooded along with waste material and soil that posed a threat to the farmers. The heavy rainfall of August affected around 57000 ha of cultivated land which may account for a loss of 1356.5 crores. Paddy and banana were the worst affected agricultural products which increased the farmer's financial burden (Sudheer *et al*., 2019).

The farmer's life had a huge impact due to the effect of flood; the sudden wave swept away their crops. Not only their fields but also their houses, livestock, aquaculture, farm equipment, and so on have been affected by the surge. According to a post-flood assessment study by Santhi and Veerakumaran (2019) in Edathua panchayath of Alappuzha district, it was found that both agriculture and allied sectors faced a severe setback due to 2018 Kerala flood. After the flood, the production was nil, therefore there was a huge decline in the sales of paddy, vegetables, pepper, and plantains. Flood also has significant effects on allied industries. In the case of livestock, excellent climatic condition is needed for their better lactation. But the animal has experienced a lot of stress during a flood, lack of sufficient feed, which has resulted in a reduction of its yield.

2.3. FLOOD AND SOIL QUALITY

Floods may result in increased or decreased nutrient content in the soil. The environmental advantages of flooding, however, come at high price when there is severe flooding, as natural structures can no longer be immune to the impact of massive and extreme floods. The most important environmental factor which causes inhibition of growth and injury in flooded plants is oxygen deficiency (Visser *et al*., 2003).

On continuous flooding, anaerobic conditions develop, and the microorganisms will use the available soil oxygen in order to survive. This will result in the depletion of free oxygen in the soil within a few days of flooding (Walls *et al.*, 2005).

Visser and Pierik (2007) indicated that the slow gas diffusion rate favours accumulation of ethylene in root systems to concentrations that may strongly affect root elongation.

Heavy floods in tropical regions have resulted in serious consequences due to extreme rainstorms, hurricanes, snow melting and dam failures (Jeb and Agarwal, 2008). Floods lead to food crop shortages due to the loss of whole harvest and the degradation of soil quality.

Shahid *et al*. (2013) observed a subsequent deterioration of soil quality under submergence probably because of insufficient organic recycling and the imbalanced use of fertiliser.

2.3.1. Effect of Flooding on Soil Attributes

Flooding of an air-dry soil damages the structure of the soil by disturbing the aggregates. Sodic soils exhibit pronounced aggregate breakdown on flooding, while soils high in iron and aluminium oxides or organic matter suffer little aggregate disruption. The structure of soil can be partly restored during drying and reoxidation by soil cracking and cementing with hydrated ferric oxides (Sanchez, 1976).

If an acidic soil is held inundated, the pH decreases and in alkaline soils, the reverse occurs. The pH increase in acid soils is primarily attributable to the Fe3+ reduction to Fe2+. The accumulation of CO_2 results in the decrease in pH of sodic and calcareous soils and a regulation on the pH rise of acid soils. An influx of dissolved and suspended nutrients, accumulation of nitrogen, increase in potassium concentration in the soil solution, increase in solubility of phosphorus and silicon are the beneficial chemical effects of flooding on soil fertility (Ponnamperuma, 1984).

Flooding drastically influences the soil physico-chemical properties, most notably soil redox potential, pH and O_2 level, thus creating situations of hypoxia or anoxia (Parent *et al*., 2008). The limited available soil oxygen will also get depleted due to use by microorganisms.

Gao *et al*. (2008) investigated the physical property heterogeneity under subsurface irrigation and flood irrigation, and the findings showed that the heterogeneity of the soil physical properties were different between subsurface irrigation and flood irrigation. The density of soils of subsurface irrigation was lower by 6.71 per cent compared to flood irrigation. The total soil porosity, non-capillary porosity and capillary porosity of subsurface irrigation was higher 11.62 per cent, 43.84 per cent and 8.72 per cent than that of flood irrigation respectively. There was significant difference in soil particle size distribution between two irrigation ways. The soil of subsurface irrigation had more clay and silt content and less sand and coarse sand content compared to flood irrigation.

Unger *et al*. (2009) studied the effect of short duration floods (3 versus 5 weeks) with varying flow rates (stagnant versus flowing) on soil inorganic nitrogen or polyphenolic content. Generally, in the soils under flooded conditions, there will be accumulation of phenolic compounds. However, his results demonstrated that short-duration floods have not led to polyphenolic accumulation in the soil. Other soil chemical changes such as total nitrogen and total organic carbon, were marginal and not despite of the development of anaerobic soil conditions.

Soil nutrients are dissolved during floods and are transferred from seasonal floodplain surfaces in to neighbouring rivers. And soil nutrients can also be transferred by lateral flow from the river to seasonal floodplains (Ubuoh *et al*., 2016).

Despite the major environmental impacts of floods, flood plays an important role in preserving crucial functioning of the eco-system and biodiversity in many natural systems. Flood may result in the deposition of organic matter, vital nutrients and minerals from oceans and rivers on to the land making soil more productive, fertile and green (Ubuoh *et al*., 2016).

The immersion of aerobic soils into water reduces their Eh which, depending on soil and particularly organic and reducible species (nitrate, sulfate and ferric iron), drops and becomes stable range from +200 mV to -300 mV (Siam *et al*., 2019).

Li *et al.* (2018) examined soil microbial population and enzyme activity responses to changes in moisture: constant submergence, five cycles of submerging-draining (S-D cycles), and constant moisture content at 40 per cent water-holding capacity (low moisture). Enzyme activities under low moisture were higher than those under S-D cycles or submergence. Reduced enzyme activity in flooded soil is associated with changes in microbial population, reduced enzyme production or increased inhibitors such as free metal ions. The composition of the soil microbial population was sensitive to alterations in soil moisture, whereas the soils under submergence and S-D cycles had higher phospholipid fatty acids (PLFA) compared with low humidity soils. Microbial biomass increased eight times in the subsurface soils after drying/rewetting relative to that under constant moisture. Soil moisture regimes have directly and indirectly influenced microbial population through effects on nutrient availability and oxygen concentrations. Waterlogging with lower oxygen levels contributes to the introduction of facultative and obligate anaerobic microorganisms.

Leno and Moossa (2019) studied the dynamics of potassium fractions under submergence in sandy clay and loamy sand rice soils of Pattambi and Onattukara sandy soils, respectively. After 15 days of submergence in Pattambi soils and after 20 days in Onattukara soils, a steady decrease in water soluble K fraction occurred. A substantial increase in the fixed potassium was observed after 30 days of submergence (284.4 mg kg^{-1}) and on 50 days of submergence (290.6 mg kg^{-1}) in Pattambi soils. The fixed potassium fraction in Onattukara soils did not change significantly. Neither the added K nor the period of submergence could bring about a change in the clay mineral lattice which accommodates the K fraction of the lattice.

Bai *et al*. (2020) studied the effects of flooding frequencies on soil carbon and nitrogen stocks in river marginal wetlands in ten-year period. Floodplain wetlands with higher flooding frequencies (i.e. permanently flooded, one-year, and five-year floodplains) recorded higher soil organic carbon and nitrogen stocks compared to lower-flooding-frequency floodplains (i.e., ten-year and one-hundred floodplains), and the highest soil organic carbon and total nitrogen stocks in top 10 cm appeared in one-year floodplain rather than permanently flooded floodplain in both years. This suggested that higher flooding frequencies could lead to soil carbon and nitrogen accumulation compared to lower flooding frequencies due to better hydrological conditions.

2.4. SOIL HEALTH AND SUSTAINABILITY

According to Doran and Zeiss (2000), soil health is characterised as the soil’s continuing capacity for life, recognizing that it consists of biological elements, which are essential to the functioning of its environment within its land use borders. Such functions are capable of sustaining soil bio-productivity, preserving the consistency of air and water surroundings and promoting plants, animals and human. Soil conservation is vital to all agricultural systems, but there is evidence of the widespread degradation, loss of organic matter, pollution, compaction, salinity, and other harms in agricultural soils.

In the words of the Midwest farmer Tom Franzen in the United States, ‘sustainable farming – sustain the people and safe guard land’. Soil quality is regarded as a significant link between agriculture management approaches and achieving the key sustainable agriculture goals. So, the quality or health of the soil and the course of transition over time are the key indicators of sustainable land management (Doran and Zeiss, 2000; Semenov and Semenova, 2018).

While soil is generally recognized for its contribution to the productivity of plants, the soil also affects the quality of water and air. Intensive land management activities and the consequent disparity in soil fertility (carbon, nitrogen) and imbalance in water recycling has depleted the quality of water in many places around the world. Among the non-point sources of water pollution in United States, agriculture has been the most common contributor. Nitrate nitrogen, whose primary sources are conversion of non-managed land into intensive agriculture, livestock waste, soil deposition and agricultural fertiliser, is the main water contaminant in North America and Europe. In the last 30 years, the rate of nitrogen input into terrestrial habitats has nearly doubled due to human alterations of the nitrogen cycle, which have contributed to substantial rises in nitrogen transfer from land and to rivers, estuarine, and sea coasts (Ramesh *et al*., 2017). Moreover, these management activities can affect air quality also. Soil quality and soil health are determining agriculture sustainable development, environmental quality, as well as outcome of both, affects plant, animal, and human health (Doran and Zeiss, 2000).

In particular, soil quality or soil health assessments are necessary to identify production areas with problem issues, to produce a realistic estimate of food production, to monitor changes in agricultural management in sustainable and environmental quality, and to support public agencies in formulating and assessing sustainable agriculture and land use (Doran and Zeiss, 2000).

Soil health refers to the soil’s ecological equilibrium and quality, and its capacity to sustain a well-balanced environment with a high degree of biodiversity and productivity above and below the surface (Cardoso *et al.,* 2013).

Soil quality is related to what it does (functions), while soil health treats soil as a living biological entity that affects plant health. Improvements in soil health, together with increased water and nutrient availability, increases soil resilience against extreme climatic events (e.g., drought, heat wave) and impart disease-suppressive attributes (Lal, 2016).

2.5. SOIL QUALITY

2.5.1. Historical Perspective

A description of soil quality was developed by Larson and Pierce (1991) and proposed that soil quality is a composite of physical, chemical and biological properties. These three properties together support plant production, control water flow, and serve as a buffer for the environment. Romig *et al.* (1995) started using score cards to determine soil quality.

Romig *et al.* (1995) indicated that soil quality and soil health can be used in the same way as farmers favoured the term ‘health’ and scientists favoured the term ‘quality’.

Soil quality is defined as ‘the ability of a soil to work within natural or controlled ecosystem boundaries, to uphold the productivity of plants and animals, hold water and air quality, and encourage human health and habitat (Karlen *et al.*, 1997).

Johnson *et al*. (1997) put forward that, soil quality is a measure of the condition of the soil in accordance with the needs of one or more people and needs or goals of a person.

Soil quality is the soil’s capacity to function. According to Nortcliff (2002) the functions are i) To provide the living species with a physical, chemical and biological environment ii) Regulate and divide the flow of water, store and recycle nutrients and other elements iii) aiding plant production and animal productivity for biological activity and diversity iv) filter and detoxify organic and inorganic matter v) offer the living organisms and their structures mechanical support. Agricultural practices affect the physical, chemical, and biochemical properties of soil. If environmental management is not enforced, such activities can lead to unintended effects such as soil erosion and loss of soil organic matter.

Several soil physical functions such as water retention and infiltration or soil aeration are directly related to the soil system's biological status, as are the types of species and nutrient supplies. Hence, soil quality is a multifunctional concept (Rosa and Sobral, 2008).

2.5.2. Assessment of Soil Quality

Larson and Pierce (1991) identified five soil functions that can be used as criteria for evaluating soil quality: retaining and releasing water to plants, streams, and sub-soils; retaining and releasing nutrients and other chemicals; promoting and sustaining root growth; maintaining soil biotic habitats; and reacting to management and resisting degradation.

Both intrinsic and dynamic properties and processes interacting within a living dynamic system determine the quality of the soil. Soil quality depicts biological chemical and physical properties, processes and interactions in the soil (Karlen *et al.*, 2003).

The importance of assessing soil quality in modern soil science added increasing public interest in sustainability and need to establish the effects of soil and management practices on soil resources (Rosa and Sobral, 2008).

Lima *et al.* (2013) pointed out that it remains difficult to achieve consensus on a collection of standardized indicators.

It is proposed that soil quality can be used for practical purposes to determine effects on crop production, erosion, soil and surface water status and quality, food and air quality (Wang *et al*., 2012).

2.5.3. Soil Quality Indicators

As indicated by Singer and Ewing (2000), the prevailing soil quality indicators at micro- and macro- farm scale include three categories: physical indicators, chemical indicators, and biological indicators. Various scientists observed different set of key indicators for soil quality assessment depending on the soil types and other differences.

The changes in soil quality indicators are used to assess whether soil quality increase, remain stable, or decline with the changes in the management, land use, or conservation practices (Brejda *et al.*, 2001). Selecting measures that are specifically related to soil quality is ideal for evaluation of soil quality. When a set of attributes is chosen to reflect the soil functions and the correct measurements are taken, the soil quality can be assessed using the data.

According to Arshad and Martin (2002), indicators of soil quality refer to measurable soil attributes which influence soil capacity to perform crop production or environmental functions. The soil attributes suggested by them include soil-depth, organic matter, respiration, aggregation, texture, bulk density, infiltration, availability of nutrients and retention capacity.

Indicators are a set of measurable attributes derived from functional relationships that can be monitored through field observation, field sampling, remote sensing, survey, or existing knowledge compilation. The properties selected can differ, depending on the type of function under consideration (Nortcliff, 2002).

Choudhary *et al*. (2005) evaluated alluvial soils and found that total soil N, available P, dehydrogenase activity and mean weight diameter (MWD) of aggregates were the key indicators.

Shukla *et al.* (2006) indicated that soil organic carbon holds an important role in the monitoring of soil quality.

Soil quality indicators could be grouped in to three large categories (USDA, 2006). Attributes include, pH, salinity, nutrient availability, cation exchange capacity, heavy metal concentration, buffering capacity of soil are the major attributes taken as chemical indicators (Nortcliff, 2002).

For short term assessments biological attributes are often chosen because they are dynamic and sensitive to changes in soil conditions. Biological attributes include populations of microorganisms and macro organisms, respiration rate or other microbial activity measures (Arshad and Martin, 2002). It is important to understand what type of information is being collected when measuring soil enzyme activity, and how it can be used. Taylor *et al*. (2002) mentioned that the soil enzymes informs about the biochemical potential, resilience and potential for soil system manipulation.

Physical indicators provide details relating to soil aeration and hydrologic status, such as infiltration and soil ability to retain water in the root zone. Nutrient availability, plant growth and rooting depth and volume is affected by physical properties of soil. The ability of a soil to endure physical forces like splashing raindrops, rapid entry of water to soil that lead to aggregate breakdown, soil dispersion and soil erosion are related to the physical properties of soil. The widely used physical indicators for evaluating soil function and quality are aggregate stability, bulk density, infiltration, available water capacity, slaking, soil crusts, soil structure and macropores (USDA, 2006).

According to Adeboye *et al.* (2011), in tropical agroecosystems, soil organic carbon, soil total nitrogen, and soil microbial biomass carbon and nitrogen could be used as the indicators to assess soil quality.

Singh *et al*. (2014) examined measures of soil quality in the arid Indian ecosystem which are under continuous cultivation systems. The results showed thatthe components of each soil cultivation system have a great influence on the soil properties such as bulk density, mean weight diameter, available phosphorus, availablepotassium and dehydrogenase activity. The negative impact of the soil cultivation system on the SQ indicators led to soil quality being degraded.

2.5.4. Concept of Minimum Dataset

A minimum dataset (MDS) is the minimum number of indicators that is required to be measured in order to assess changes in soil quality from different management systems (Arshad and Martin, 2002). The first step is choosing the suitable soil quality indicators to effectively track critical soil functions as defined by the particular management goals for which an assessment is being made.

Nortcliff (2002) pointed out that indicators of soil quality should be selected on the basis of soil functions under study and threshold values should be determined based on local conditions to produce a valid soil quality index.

Rezaei *et al*. (2006) used a general approach for choosing the most representative indicators from large existing data sets to develop a method for the selection of suitable predictive indicators to assess the soil quality, for mountainous rangeland in northern Iran.

Together these indicators form a MDS which can be used to evaluate the performance of the essential soil functions allied with each management objective (Sharma and Mandal, 2009).

Selection of indicators may be made based solely on statistical methods, seeking expert opinion or a combination of both to attain a minimum dataset (Lima *et al.,* 2013). They showed that a minimum data set of eight out of the total twenty-nine indicators gave sufficient management information on various soil quality variations among the management systems.

Joseph (2014) had done soil quality assessment with the help of statistical tool, principle component analysis (PCA) in *Pokkali* soils. The principle component analysis of 28 attributes resulted in minimum data set (MDS) containing 13 attributes. MDS included available water, pH, sand percent, aggregate stability, silt percent, available magnesium, bulk density, available sulphur, MBC0, available manganese, organic carbon, base saturation and electrical conductivity for assessing soil quality in *Pokkali* tract.

Biswas *et al*. (2017) carried out the soil quality assessment in three soil orders under rice cropping system. The principal component analysis of 24 attributes in Inceptisols resulted in a MDS of 4 attributes which are available zinc, bulk density, β-glucosidase activity and urease activity from PC1, PC2, PC3 and PC4 respectively. Similarly, PCA of 26 attributes in Entisols and 27 attributes in Alfisols gave a MDS of 4 attributes each.

Juhos *et al*. (2019) interpreted the soil quality indicators for land suitability assessment in Central European arable soils. According to the intercorrelation of input indicators and variance of scored indicators the minimum data set for soil quality assessment consisted of texture, depth of groundwater table, soil organic matter, pH, Na, available K, P and Zn.

2.5.5. Soil Quality Index

In the agricultural and environmental sense, the soil quality index defines the goodness of a soil to have higher crop productivity, better response rate for fertilisers, stable crop production and good soil environment maintenance. The Soil Quality Index (SQI) combines the soil's calculated physical and chemical properties into a single parameter which could be used as an indicator of overall soil quality for agriculture. Soil quality cannot be measured explicitly but soil properties can be used as measures that are immune to changes in management. Soil quality is diverse in nature and can influence land use sustainability and productivity. Soil quality is the end result of processes of soil degradation or regeneration, and is influenced by soil chemical, physical and biological components of soil and their interactions. A single list of quality indicators cannot be created which is ideal for all purposes. It is advisable to use a number of possible soil quality indicators rather than a single indicator. Soil quality index is worked out in three steps. The key steps are to pick a minimum data set of indicators best depicting soil function, scoring the MDS indicator upon on the performance of soil function, and incorporating the indicator scores into a comparative soil quality index. Suitable soil quality indicators are to be selected and these indicators collectively form the minimum dataset (Andrews *et al.,* 2002).

Andrews *et al.* (2002) carried out standardized principal component analysis (PCA) of all the untransformed data for the collection of MDS, showing statistically significant discrepancies between management systems using ANOVA. Principal components (PCs) for a data set are described as linear combinations of variables that account for maximum variance within the set by representing vectors in *p*-dimensional space closest to n observations, subject to orthogonal interaction. PCA may be used for choosing a subset from a wide collection of data. They presumed that system attributes were best reflected by PCs receiving high values. Therefore, it is important to pick only PCs with own values >1. When transformed the MDS variables were weighted were weighted using PCA results for each observation. Every PC resolved a certain amount of the variability (%) in the total data set. This percentage is then divided by total percentage of variation by all PCs with their own vectors greater than one. And this provides the weighting factor for variables under a PC. The SQI is then calculated using the formula, assuming that higher index score indicated better soil quality (Andrews *et al.*, 2002).

Dongare (2010) assessed soil quality index in Godavari canal command area and found the soil quality indicators like Ca/Mg ratio, organic carbon, calcium carbonate, ESP, EMP were retained on the minimum data sets for calculating the soil quality index by principle component analysis. This indicated that the soil quality index for soils at the head and mid ridge was high (1.18) and poor at the tail edge (0.76) due to salinity and sodium degradation in the commanding region of the tail. In determining the soil quality, the Ca/Mg content was identified as the most important indicator for soil quality followed by organic carbon and exchangeable sodium percentage (ESP).

The method suggested by Karlen and Stott (1994) to calculate the SQI was followed by Lima *et al.* (2013). To assess the effects of various forms of soil management on soil quality, they selected soil functions correlated with soil quality. Such functions have been weighted and combined by the following expression:

Soil quality index = qwe (wt) + qwt (wt) + qrd (wt) + qspg (wt)

where wt is the numerical weight which is given for each soil function under study, qwe is the rating for soil's capacity to tolerate entry of water, qwt is the rating for soil's capacity to aid movement of water, qrd is the rating for the soil's capacity to endure degradation, qspg is the rating for the capacity of soil to support plant growth.

Remote sensing and geographical information systems (GIS) could be exploited for the determination of soil quality (Obade and Lal, 2013).

Although several soil quality and soil health indicators and indices have been proposed, a universally appropriate and relevant description and methodology for soil quality or soil health assessment is still not in place (Laishram *et al.,* 2012).

Mukherjee and Lal (2014) compared three widely used methods to estimate soil quality index using the data collected from 72 soil samples from three on-farm study sites in Ohio: (i) simple additive SQI (SQI-1), (ii) weighted additive SQI (SQI-2), and (iii) statistically modelled SQI (SQI-3) based on principal component analysis (PCA). The benefit of using simple additive SQI is that after measuring any number (low to high) of soil parameters the soil quality could be measured and this methodology is much simpler compared to other approaches as the scoring requires literature review and expert opinions only. The downside of simple additive SQI is that it is subjective, which relies primarily on the point of view of the researcher. On the other hand, advantage of weighted additive SQI is that it includes weightage based on the design of the study, system or the dataset to offset the subjectivity of the approach present in weighed additive SQI. The downside of weighted additive SQI, however, is that it needs numerous numbers of soil parameters under different soil functional systems which in practical cases can be costly and time consuming. The statistically modelled SQI is advantageous in the aspect of its ability to predict soil quality based on a reduced dataset with low number of soil parameters. Moreover, it is largely an objective method, since the statistical technique will pick a small number of soil parameters required to measure SQI based on the variances present in the entire dataset. So, statistically modelled SQI can be used effectively in a long-term aspect of a particular soil/crop framework once it has assessed the most important soil parameters necessary to determine the soil quality of a particular soil/crop/management scenario.

Joseph *et al*. (2014) assessed the soil quality of five different land uses of pokkali and the observed soil quality index value was in the order, paddy-shrimp> paddy alone> fallow> mangrove> shrimp alone.

Pable *et al*. (2016) assessed the soil quality of two major cotton growing agro ecological sub regions (AESR) of Vidarbha region of Maharashtra, AESR 6.3 and AESR 10.2. For the determination of soil physical, chemical and biological indicators, twelve profiles have been defined. For determination of soil quality indicators, minimum dataset approach was used. The soil quality index was determined for each pedon on the basis of 13 soil characteristics derived from five principal components of Eigen values > 0.9. The SQI was the highest in pedon 3 (1.63) of agro ecological sub region 6.3 and pedon 12 (1.85) of agro ecological sub region 10.2.

2.5.6. GIS AND SOIL MAPPING

Remote sensing techniques play a significant role in soil and land degradation mapping, monitoring of degraded lands, soil fertility assessment, soil water conservation, soil moisture assessment, and soil suitability studies. Geographic information system (GIS) is a technical field that in-corporates geographical features with tabular data for mapping, analysing, and assessing real world problems (Swathi and Rani, 2019). GIS enables maps to be overlaid with various thematic maps (e.g. soil and land use, watershed, district, village maps) and thus promotes map incorporation and analysis.

2.5.7. The Global Positioning System (GPS)

GPS is a satellite-based navigation and survey system for precise position and time determination, using satellite radio signals, in real-time or post-processing mode. GPS is used worldwide for various navigational and positioning purposes, including land, air and sea navigation, determining the precise coordinates of important geographical features as an integral input to the mapping and Geographical Information System (GIS). It is also used in cadastral survey, earthquake, landslide, and guidance of vehicles using GPS-GIS integrated system. In India also, GPS is used by various organisations for numerous applications in various fields such as aircraft and ship navigation, surveying, geodesic control networks, crustal deformation study, cadastral survey, GIS database building, time service etc (Kulkarni, 2000).

Georeferencing is the method of integrating geographical coordinates with a digital map so that it is correctly associated with the globe. Georeferencing allows the proper alignment of two separate digital maps. All digital maps are not georeferenced. For precise agriculture, however, most maps were produced with GPS, for which synchronisation is determined when the data is collected and then georeferenced. Georeferencing is a central principle on which all GIS functions are based (Dash *et al*., 2018).

2.5.8. Soil Mapping

In this process, remote sensing techniques significantly reduce fieldwork and soil boundaries are more squarely delineated as opposed to traditional methods (Rao *et al*., 2004).

Approach of satellite data interpretation, soil landscape delineation, soil survey and collection of samples, analysis of soil samples for physical and chemical properties, legend planning, correlation, classification and finalisation of maps are the main procedures involved in soil mapping (Rao *et al*., 2004).

Mathews *et al*. (2009) mapped the nutrient status of available nitrogen, phosphorous and potassium in the soils of Mirjan village of Karnataka. They stated from the maps that, 247.3 ha were low in nitrogen, 86.5 ha were medium in nitrogen content and 22.1 ha were high in nitrogen of the total study area. Available phosphorous was low in 249.3 ha, medium in 88.4 ha and high in 18.3 ha, whereas potassium was low in 159.2 ha, 131.7 ha were medium and 56.39 ha were high.

Kumar *et al*. (2010) prepared soil fertility maps based on Geographical Information Systems (GIS) using Punjab's ArcGIS 9.2 software to ease the planning process and developed detailed fertilizer recommendations for productive and cost-effective fertiliser use. GIS based maps shows that 34.98 per cent of the state's total area is low, 47.79 per cent medium and 17.22 per cent high in organic carbon.

Soil fertility maps developed based on GIS serve as a decision support tool for nutrient management. It helps to adopt a rational approach compared to farmer's practices or blanket use of fertilisers and reduce the need for wide plot-by-plot soil testing (Iftikar *et al.,* 2010).

Hence, Soil mapping is a complex process involving the identification, description and delineation of different soil attributes based on area's physiography, vegetation and climate, confirmation through field research and laboratory evidence, and depiction on a standard base map (Wadodkar and Ravisankar, 2011).

Davatgar *et al*. (2012) estimated the spatial variation of clay, pH, cation exchange capacity, organic carbon, total nitrogen, available phosphorous, and available potassium using geostatistical technics, and further delineated soil fertility management zones using principal component analysis (PCA). Analysis of variance has shown that soil fertility status is heterogeneous. The mean values of soil nutrients in each zone can be used as a guideline for fertilization at variable rates.

Ramu (2016) performed the mapping of soil chemical properties by GIS technique in Udham Singh Nagar district of Uttarakhand and indicated that majority of the soils of the study area was moderately alkaline in reaction, normal EC, low to medium in available N, medium in available P, medium to high in both available K and S content.

Geostatistical mapping is the development of thematic-based maps by the use of geostatistical analysis, which shows the overall variation of an environmental variable over a study area. In ArcGIS, the geostatistical analyst tool enables various spatial interpolation methods to forecast sample values at unknown locations while providing uncertainty measurements corresponding to the predicted values. These predicted values are described in the form of maps of the variable that is being modelled (Khatri, 2018).

The methods of spatial interpolation involve deterministic methods of spatial interpolation involves Inverse distance weighted, Global polynomial interpolation and radial basis functions and non-deterministic or probabilistic methods or statistical methods of spatial interpolation involves kriging, cokriging, and splines (Khatri, 2018).

Mini and Mathew (2018) identified and mapped the spatial variability of soil fertility in a coconut based agroecological unit in the sandy plains of Kerala. Thematic maps showed low organic carbon status in 74.2 per cent, available phosphorus in 0.6 per cent and available potassium in 82.6 per cent area. The deficiency of calcium and magnesium was found in 96.8 per cent area and deficiency of sulphur in 8.6 per cent area. Fe and Mn were sufficient in the soils. Boron was deficient in 93.1 per cent area of this sandy tract.

Balasubramanian *et al.* (2020) prepared soil fertility maps of Salem district of Tamil Nadu which revealed that, major area of Valapadi block of Salem district, upland of Tamil Nadu is alkaline, non-saline and low in organic carbon, low in available nitrogen, medium in available phosphorus and high in available potassium.

Materials and Methods

3. MATERIALS AND METHODS

The study entitled 'Assessment of soil quality in the post-flood scenario of AEU 14 in Idukki district of Kerala and generation of GIS maps' involved the study of soil quality in terms of physical, chemical and biological attributes. A detailed account of the site characteristics, sampling, experimental material used, and methodology adopted during the course of study has been presented under the following subheads:

3.1. General description of the study area

3.2. Collection and preparation of samples

3.3. Physical, chemical and biological attributes of soil

3.4. Soil quality index

3.5. Nutrient index

3.6. Land quality index

3.7. Generation of GIS maps

3.8. Statistical analysis

3.1. GENERAL DESCRIPTION OF THE STUDY AREA

3.1.1. Location

Six severely flood affected panchayaths, *viz*. Mariyapuram, Vazhathope, Kanjikuzhy and Kamakshy in Idukki block, Konnathady in Adimali block and Rajakkad in Nedumkandam block (Table 1) were selected in agro-ecological unit (AEU) 14 designated as Southern High Hills of Idukki district. The terrain is undulating, hilly and marked with elevations and depressions. Georeferenced location map of the study area is given in Fig. 1.

Table 1. Location details of sampling sites

Sl. No	Panchayath	No. of samples	Sampling points	Latitude	Longitude
1.	Vazhathope	12	1	9.884820 °N	76.903018 °E
			2	9.851208 °N	76.926212 °E
			3	9.861449 °N	76.956500 °E
			4	9.860316 °N	76.958572 °E
			5	9.880383 °N	76.931887 °E
			6	9.888355 °N	76.963406 °E
			7	9.907533 °N	76.938611 °E
			8	9.898459 °N	76.968440 °E
			9	9.862970 °N	76.908946 °E
			10	9.876097 °N	76.948900 °E
			11	9.896091 °N	76.934237 °E
			12	9.852670 °N	76.959085 °E
2.	Kamakshy	13	13	9.826742 °N	77.021002 °E
			14	9.824854 °N	77.033958 °E
			15	9.838424 °N	77.046276 °E
			16	9.817761 °N	77.044753 °E
			17	9.822128 °N	77.060584 °E
			18	9.830141 °N	77.023895 °E
			19	9.838005 °N	77.016233°E
			20	9.853884 °N	77.044432 °E
			21	9.845592 °N	77.033125 °E
			22	9.841424 °N	77.038636 °E
			23	9.855388 °N	77.016363 °E
			24	9.846665 °N	77.012978 °E
			25	9.844168 °N	77.021362 °E
3.	Konnathady	12	26	9.930774 °N	77.026676 °E
			27	9.944193 °N	77.015834 °E
			28	9.939123 °N	76.996386 °E
			29	9.951642 °N	77.001915 °E
			30	9.966192 °N	77.004806 °E
			31	9.966718 °N	77.038818 °E
			32	9.958159 °N	77.013978 °E
			33	9.955084 °N	77.035397 °E
			34	9.919781 °N	77.049317 °E
			35	9.935277 °N	77.064722 °E
			36	9.911396 °N	77.077828 °E
			37	9.934722 °N	77.045833 °E

continued….

Table 1. Location details of sampling sites (continued…)

Sl. No	Panchayath	No. of samples	Sampling points	Latitude	Longitude
4.	Rajakkad	15	38	9.966133 °N	77.096334 °E
			39	9.968989 °N	77.075657 °E
			40	9.947312 °N	77.090633 °E
			41	9.980918 °N	77.114468 °E
			42	9.968055 °N	77.114722 °E
			43	9.968055 °N	77.114722 °E
			44	9.972733 °N	77.115420 °E
			45	9.962032 °N	77.098146 °E
			46	9.955715 °N	77.110507 °E
			47	9.947011 °N	77.082528 °E
			48	9.960336 °N	77.080434 °E
			49	9.938936 °N	77.097295 °E
			50	9.961972 °N	77.106591 °E
			51	9.962254 °N	77.061303 °E
			52	9.975411 °N	77.067759 °E
5.	Mariyapuram	13	53	9.837644 °N	76.988303 °E
			54	9.830405 °N	77.010713 °E
			55	9.845151 °N	76.984602 °E
			56	9.853813 °N	76.981731 °E
			57	9.833478 °N	76.995778 °E
			58	9.866359 °N	76.977542 °E
			59	9.877620 °N	76.976344 °E
			60	9.858130 °N	76.992061 °E
			61	9.847315 °N	76.996887 °E
			62	9.869229 °N	76.993873 °E
			63	9.886528 °N	76.977126 °E
			64	9.881980 °N	77.004141 °E
			65	9.892436 °N	76.998047 °E
6.	Kanjikuzhy	13	66	9.912124 °N	76.965598 °E
			67	9.943048 °N	76.970563 °E
			68	9.919753 °N	76.953907 °E
			69	9.943852 °N	76.959246 °E
			70	9.936196 °N	76.942529 °E
			71	9.945348 °N	76.937292 °E
			72	9.952590 °N	76.934101 °E
			73	9.962611 °N	76.922712 °E
			74	9.966875 °N	76.909283 °E
			75	9.976155 °N	76.890723 °E
			76	9.963376 °N	76.912682 °E
			77	9.940715 °N	76.946926 °E
			78	9.937258 °N	76.955844 °E

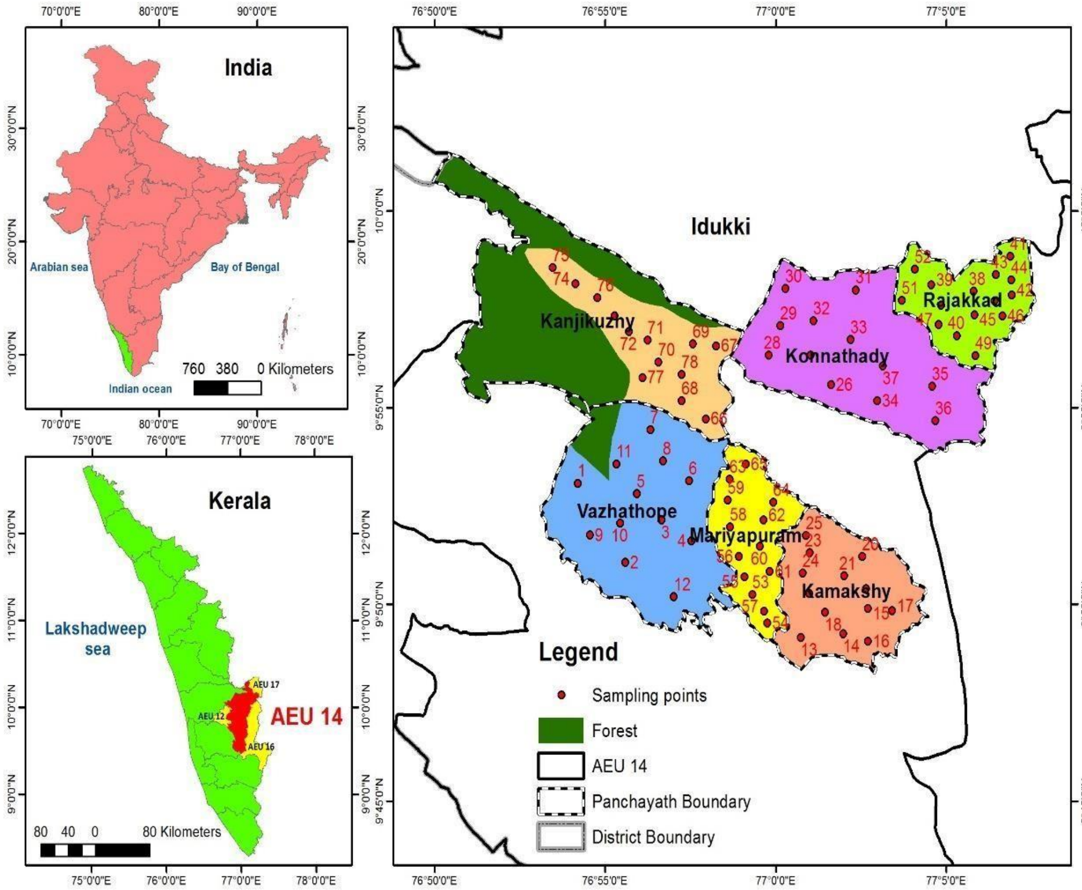

Fig. 1. Georeferenced location map of the study area in AEU 14 of Idukki district

3.1.2. Weather data

The monthly average values of the different weather parameters in AEU 14 of Idukki district during the period from May 2018 to May 2019 are presented graphically in Fig. 2. The deviation of rainfall and number of rainy days in the year 2018 from the average monthly rainfall over the last ten years is presented in Table 2.

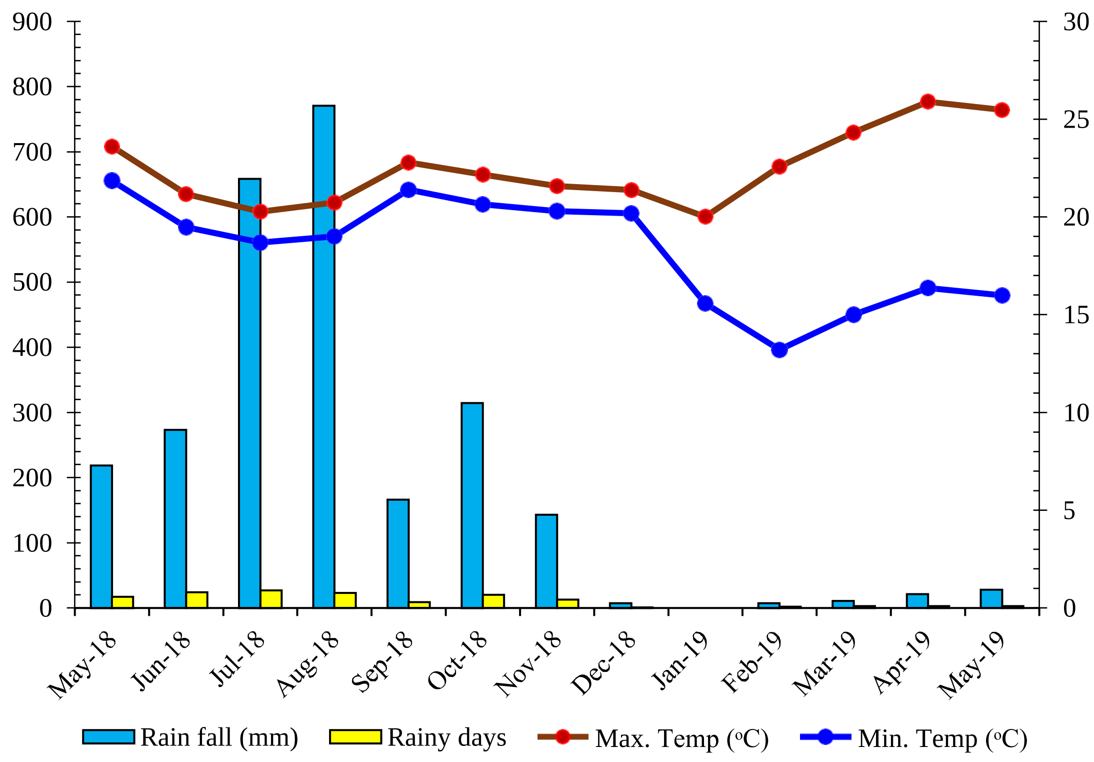

Fig. 2. Monthly mean of weather parameters in AEU 14 of Idukki district

Table 2. Deviation in rainfall during 2018 from the average monthly rainfall over the previous ten years in AEU 14 of Idukki district

Month	Average rainfall (2008-2017)	Rainfall during 2018	Deviation in rainfall	Average no. of rainy days (2008-2017)	No. of rainy days during 2018	Deviation in no. of rainy days
	(mm)			(days)		
January	15.6	2	-13.6	1	1	0
February	13.0	24	+11.0	1	3	+2
March	50.5	83	+32.5	4	5	+2
April	100.3	69.6	-30.7	6	8	+2
May	95.8	218.7	+122.9	6	17	+11
June	262.2	273.2	+11.0	18	24	+6
July	323.6	658.6	+335.0	23	27	+4
August	281.1	770.5	+489.4	20	23	+3
September	178.3	166	-12.3	16	9	-7
October	216.2	314.4	+98.3	14	20	+6
November	178.4	143	-35.4	10	13	+3
December	48.4	7.2	-41.2	5	1	-4

3.2 COLLECTION AND PREPARATION OF SOIL SAMPLES

A detailed survey based on a questionnaire (Appendix I) was conducted to identify the flood affected areas and random sampling technique was followed for the selection of sampling sites. Representative georeferenced surface soil samples (0-20 cm) were collected from 78 sites (Table 1) in Mariyapuram, Kamakshy, Kanjikuzhy, Vazhathope, Konnathady, and Rajakkad panchayaths of AEU 14 in Idukki district (Fig. 1). Each sample was air dried and divided into two parts. One part was properly ground using mortar and pestle and passed through a 2 mm sieve for analysing the soil physical (bulk density, particle density, porosity, texture, depth of silt/clay/sand deposition, water holding capacity, and soil moisture), chemical (pH, electrical conductivity, organic carbon, available primary and secondary nutrients, boron) and biological properties (acid phosphatase). The remaining part was maintained unprocessed and used for the determination of aggregate size distribution.

3.3 PHYSICAL, CHEMICAL AND BIOLOGICAL ATTRIBUTES OF SOIL

Soil samples were characterised forselected physical, chemical and biological parameters (Table 3).

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

Sl. No	Attribute	Methodology	Reference
Physical			
1.	Bulk density	Undisturbed core sampling	Black *et al*. (1965)
2.	Particle density	Standard pycnometer method	Black *et al*. (1965)
3.	Porosity	Empirical formula using bulk density and particle density	Black *et al*. (1965)
4.	Texture	Bouyoucos hydrometer method	Bouyoucos (1962)
5.	Water holding capacity	Core method	Gupta and Dakshinamurthy (1980)
6.	Aggregate analysis	Wet sieving using Yoder’s apparatus	Yoder (1936)

Chemical			
7.	pH	pH meter (1:2.5) (w/v)	Jackson (1973)
8.	Electrical conductivity	Conductivity meter (1:2.5) (w/v)	Jackson (1973)
9.	Organic carbon	Chromic acid wet digestion method	Walkley and Black (1934)
10.	Available N	Alkaline permanganate distillation and titrimetry	Subbiah and Asija (1956)
11.	Available P	Bray's extraction and spectrophotometry	Bray and Kurtz (1945)
12.	Available K	Neutral *N* ammonium acetate extraction and flame photometry	Jackson (1973)
13.	Exchangeable Ca and Mg	Versenate titrimetry	Hesse (1971)
14.	Available S	$CaCl_2$ extraction and spectrophotometry	Massoumi and Cornfield (1963)
15.	Available Boron	Hot water extraction and spectrophotometry (Azomethine-H reagent)	Gupta (1967)
Biological			
16.	Acid phosphatase activity	Colorimetric estimation of PNP released	Tabatabai and Bremner (1972)

3.4. SOIL QUALITY INDEX

3.4.1. Setting Up of a Minimum Data Set for Assessment of Soil Quality

Minimum data set (MDS) for the assessment of soil quality was set up after carrying out the principal component analysis. Since it is based on the assumption that the principal components (PCs) receiving the higher values can best represent the system attributes, only the PCs with Eigen values greater than one was examined. The contribution of each variable to the PC is represented by the weight or factor loading it received. Only the highly weighted variables (within the 10 % of the highest factor loading) from each PC were retained (Fig. 3). When more than one variable was retained in the PC, their linear correlation was calculated to determine whether the variable to be considered was redundant. Among the well correlated variables in the PC, the variables with highest sum of correlation coefficients were chosen for the MDS (Andrews *et al.*, 2002).

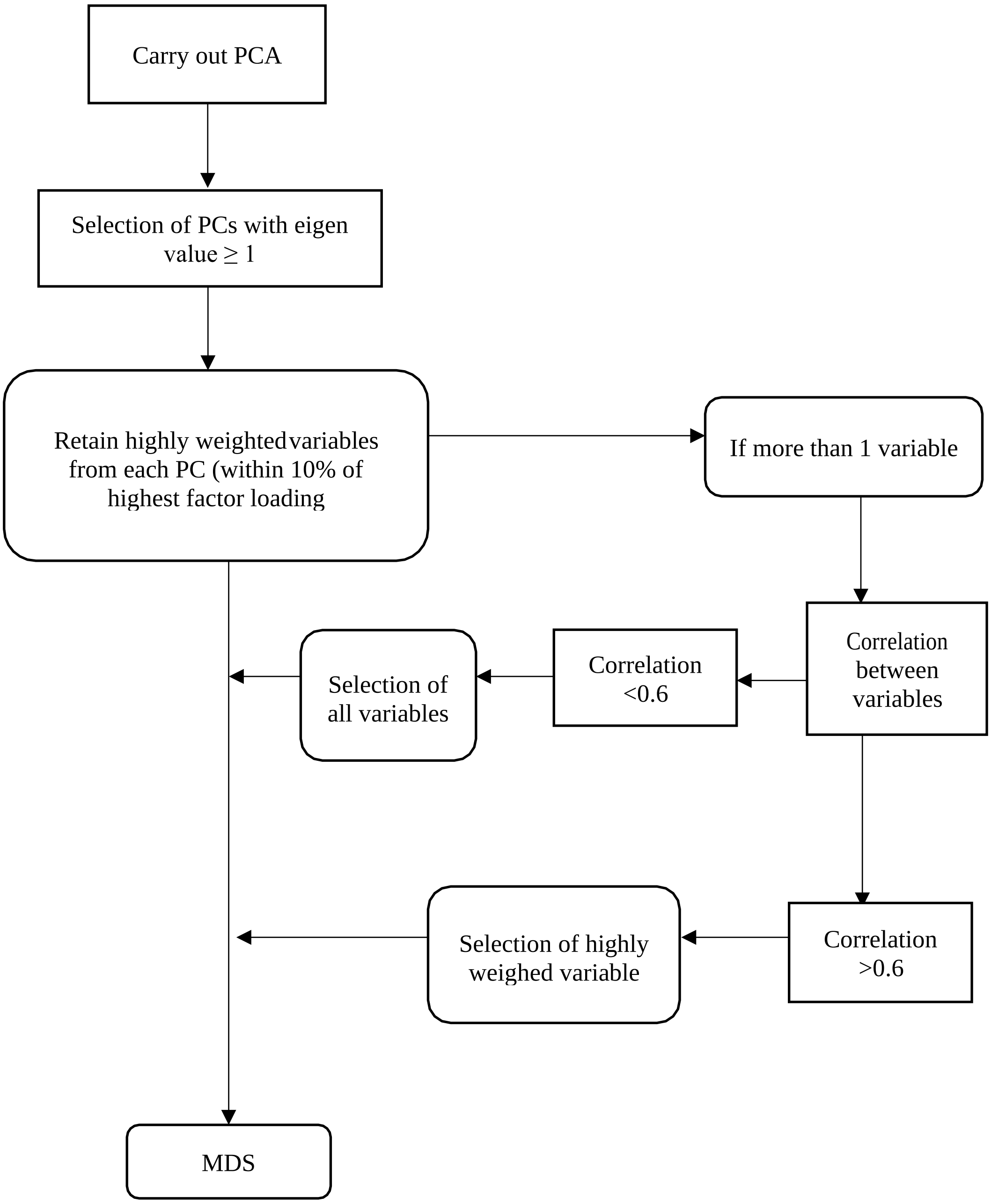

Fig. 3. Flow chart of the methodology followed for the formation of minimum dataset

3.4.2. Formulation of Soil Quality Index

The soil quality evaluation was done as per the procedure described by Larson and Pierce (1994).

The attributes in the MDS were assigned an appropriate weight. The status of each attribute was categorised into four classes *viz*. Class-I (very good status), Class-II (good status), Class-III (poor status) and Class-IV (very poor) and marks of 4, 3, 2 and 1 were assigned to the classes respectively (Kundu *et al.*, 2012; Mukherjee and Lal, 2014) with slight modifications based on the soil fertility ratings for secondary and micronutrients for Kerala soil. Soil quality index (SQI) was calculated by the equation,

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

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

The weight for each indicator was assigned on the basis of existing soil conditions, cropping pattern, and agro-climatic conditions. The sum of all weights is normalised to 100 per cent (Singh *et al*., 2017).

The change of soil quality was measured by computing the relative soil quality index (RSQI) using the concept of Karlen and Stott (1994).

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

where SQI is the computed soil quality index and SQI_m is the theoretical maximum. Then each sampling location was rated based on the RSQI value as poor (RSQI < 50 %), medium (RSQI 50 – 70 %) and good (RSQI > 70 %) (Kundu *et al.*, 2012).

3.5. NUTRIENT INDEX

The nutrient index categorization and calculation was done as proposed by Parker *et al*. (1951), using the following formula:

$$\text{Nutrient index (N.I.)} = \{(1 \text{ x } A) + (2 \text{ X } B) + (3 \text{ X } C)\}/ TNS$$

where,

A = Number of samples in low category

B = Number of samples in medium category

C = Number of samples in high category

TNS = Total number of samples

The nutrient index with respect to organic carbon, available N, available P and available K was used to evaluate the fertility status of soils in the different flood affected panchayaths. The rating chart by Ramamoorthy and Bajaj (1969) is given in Table 4.

Table 4. Rating chart of nutrient index

Sl. No.	Nutrient index	Nutrient index range	Remarks
1	Low	Below 1.67	Low fertility status of the area
2	Medium	1.67-2.33	Medium fertility status of the area
3	High	Above 2.33	High fertility status of the area

3.6. LAND QUALITY INDEX

Soil organic carbon stock was calculated by the equation given by Batjes (1996) and expressed in Mg ha^{-1}

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

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

Table 5. Rating chart of land quality index

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

3.7. GENERATION OF GIS MAPS

In the present study, ArcGIS software version 10.3 was used for spatial and attribute database generation, GIS analysis and generation of various thematic maps. Inverse distance weighting method (IDW) was used for the spatial interpolation of each attribute in the study area. IDW estimates interpolation cell values by averaging the values of sample points in the vicinity of each cell. This method assumes that the influence of value of the variable being mapped at a sampling point reduces with increase in distance from the sampling point (ESRI, 2001). The values at unknown location are determined using a weighting value and values at known locations. Weights are calculated using an equation based on the distance between the known and unknown locations and the total number of sampling points (Ogbozige *et al*., 2018).

The soil analysis data along with the respective geo coordinates were entered in MS Excel, converted into a CSV (Comma delimited) file and imported into the ArcGIS mapping software. The shape file with the boundaries of sampled panchayaths in AEU 14 of Idukki district *viz.*, Vazhathope, Kamakshy, Konnathady, Rajakkad, Mariyapuram, and Kanjikuzhy was also imported into the mapping software. IDW was selected from the spatial analyst tool. Longitude, latitude and soil attribute values were selected as x, y and z respectively and boundaries of the sampled panchayaths were taken as the processing extent in the IDW dialog box. The number of sampling points was also entered, and the data was interpolated. The output map obtained for each parameter was classified manually based on the standard ratings and different colours were allotted for each class.

3.8. STATISTICAL ANALYSIS

Correlations between soil physical, chemical and biological properties were worked out as per standard method by Panse and Sukhatme (1978) using open software OPSTAT.

Results

4. RESULTS

This chapter basically deals with the findings of the research work conducted in AEU 14 in Idukki district of Kerala related to the survey, soil sample collection, assessment and mapping of flood affected soils. The data obtained from laboratory and statistical analyses are represented in tabulated and graphical form under the following sections.

4.1. SURVEY

The survey was conducted in the severelyflood affected panchayaths of AEU 14 of Idukki district *viz*.Kanjikuzhy, Mariyapuram, Vazhathope, Kamakshyof Idukki block, Rajakkad of Nedumkandam block and Konnathady of Adimaly block.

Kanjikuzhy has a total area of 227.51 km^2 which is distributed over 18 wards. The major ecosystems in the panchayath includerivers, hills and valleys. All the wards in the panchayath were affected by either flood or soil erosion. The farmers were mostly marginal and small farmers (<2 ha).Mariyapuram panchayath comprises of a geographic area of 32.18 km^2 with a total of 14 wards. The major ecosystems in the panchayath include hills, dams and rivers. Three wards of the panchayath *viz*. Idukki (Ward 9), Kochukarimban (Ward 1) and Upputhode (Ward 2) were severely affected by flood. Upputhode (Ward 1) and Mariyapuram (Ward 10) were affected by debris flow also. Many livestock and agriculture crops were lost in flood. Vazhathope panchayath has a total number of 14 wards and a total area of 199.84 km^2. Kamakshypanchayath consists of 15 wards out of which 4wards were severely affected by flood. Kamakshi (Ward 6), Thankamani (Ward 11), Thankamani west (Ward 12) and Irukutti (Ward 15) were the most severely affected ones. All 15 wards were affected by debris flows. After flood, domestic waste got deposited in various parts of the panchayath which caused environmental pollution. Crops like coffee, cocoa, pepper and nutmeg were widely destroyed by flood. The flood also affected domestic mammals and birds like cows, goats, buffaloes and poultry. Rajakkad gramapanchayath has a total area of 31.03 km^2. The panchayath comprises of 13 wards. The area is a high land region which has hills, dams, rivers, wetlands and plantations in it. The major crops include both plantation crops like coffee, cardamom, pepper, nutmeg and vegetables like bitter gourd, cowpea. Paddy is also cultivated by many farmers. Konnathady panchayath has a total area of 96 km^2. The main ecosystems in the panchayath are hills, dams and forests. Pepper, coffee and cardamom are the major cultivations in the area.

Majority (91%) of the farmers belonged to the small and marginal (<2 ha) category (Table 6). Major crops are pepper, cardamom, nutmeg, cocoa, banana, coffee, and coconut. The farmers followed organic practices and liming integrated with inorganic fertilisers. FYM, neemcake, bone meal were used in all crops. For the primary nutrients, urea, factomphos and potash were used. For pepper, bonemeal is applied twice a year in addition to the FYM application. For cocoa, the application of organic manures varies from 2 to 3 times a year. Cardamom is well maintained with integrated nutrient management where organic manures are applied 6 to 7 times a year. For coconut, conventional fertilisers like urea, potash and factomphos were used. Liming is done once a year.

Table 6. Survey details of farmers of six severely flood affected panchayaths in AEU 14 of Idukki district

Particulars	No. of farmers	Percentage of farmers
Crops		
1. Pepper	51	65
2. Cardamom	35	45
3. Coconut	13	17
4. Coffee	15	19
5. Nutmeg	34	44
6. Cocoa	32	41
7. Banana	22	28
8. Tea	4	5
9. Cassava	3	4
10. Vegetables	5	6
11. Paddy	2	3
Nutrient management		
1. INM	51	65
2. Organic	20	26
3. Conventional	7	9
Size of holdings		
1. <2 ha	71	91
2. >2 ha	7	9

4.2 CHARACTERISATION OF SOIL SAMPLES

Soil quality was assessed by analysing the physical, chemical and biological attributes of the soil samples collected from the farmer's field of the selected six flood affected panchayaths.

4.2.1. Physical Attributes of Soil

4.2.1.1. Bulk Density, ParticleDensity and Porosity

The bulk density of soils in the different sampling points ranged from 0.90 to 1.48 Mg m^{-3} with a mean value of 1.16 Mg m^{-3}(Table 7). The lowest bulk density was observed in Rajakkad panchayath (0.90 Mg m^{-3}) and the highest bulk density was observed in Vazhathope panchayath (1.48 Mg m^{-3}). There was not much difference in the mean bulk density among different panchayaths. The mean bulk density of panchayaths Konnathady, Kamakshy, Vazhathope, Mariyapuram, Kanjikuzhy and Rajakkad were 1.19, 1.18, 1.16, 1.16, 1.14 and 1.11 Mg m^{-3}respectively.

The particle density of soils among the different sampling locations varied from 1.90 to 2.79 Mg m^{-3} with a mean value of 2.14 Mg m^{-3}(Table 7).The lowest particle density was observed in Kamakshy panchayath (1.90 Mg m^{-3}). And the highest particle density was observed in Konnathady panchayath (2.79 Mg m^{-3}). The soils of Vazhathope panchayath had the highest mean value for particle density (2.22 Mg m^{-3}). The mean particle density of panchayaths Kanjikuzhy,Mariyapuram, Kamakshy, Konnathady, and Rajakkad were 2.18, 2.13, 2.11, 2.11 and 2.08 Mg m^{-3}respectively.

The porosity of soils among different sampling points ranged from 28.8 to 55.8 per cent with a mean value of 45.8 per cent (Table 7). The highest porosity was observed in Rajakkad panchayath (55.8 %) and the lowest porosity was observed in Mariyapuram panchayath (28.8 %). The soils of Kanjikuzhy panchayath had the highest mean value for porosity (47.9 %) and the soils of Konnathady panchayath had the lowest mean value of porosity. The average porosity of panchayaths Vazhathope, Rajakkad, Kamakshy, Mariyapuramwere 47.5, 46.5, 44.1, and 45.4 respectively.

Table 7. Bulk density, particle density and porosity of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Porosity (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Vazhathope	1.16 ± 0.16	1.00-1.48	2.22 ± 0.19	2.00-2.54	47.5 ± 6.8	32.0-55.4
Kamakshy	1.18 ± 0.12	0.99-1.33	2.11 ± 0.12	1.90-2.30	44.1 ± 5.4	35.6-51.9
Konnathady	1.19 ± 0.14	1.04-1.47	2.11 ± 0.25	1.91-2.79	43.2 ± 5.7	31.4-50.5
Rajakkad	1.11 ± 0.13	0.90-1.46	2.08 ± 0.09	1.96-2.26	46.5 ± 6.9	29.4-55.8
Mariyapuram	1.16 ± 0.12	0.97-1.36	2.13 ± 0.14	1.91-2.33	45.4 ± 7.5	28.8-55.2
Kanjikuzhy	1.14 ± 0.08	1.01-1.34	2.18 ± 0.09	2.03-2.34	47.9 ± 3.1	42.8-53.4
AEU 14	**1.16 ± 0.13**	**0.90-1.48**	**2.14 ± 0.15**	**1.90-2.79**	**45.8±6.1**	**28.8-55.8**

4.2.1.2. Particle size distribution

The clay content of soils varied from 23 to 63 per cent with a mean value of 39.9 per cent (Table 8). The soils of Mariyapuram panchayath had the highest mean value (43 %) for clay content whereas the soils of Konnathady panchayath had the lowest mean value (37.2 %) for clay content.

The silt content of soils varied from 10 to 35 per cent with a mean value of 20.8 per cent. The soils of Konnathady panchayath had the highest mean value (23.3 %) for silt content whereas the soils of Rajakkad panchayath had the lowest mean value (18.0 %) for silt content.

The sand content of soils varied from 22 to 62 per cent with a mean value of 39.4 per cent. The soils of Rajakkad panchayath had the highest mean value (42.3 percent) for sand content whereas the soils of Mariyapuram panchayath had the lowest mean value (39.4 %) of sand content.

Table 8. Particle size distribution of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Clay (%)		Silt (%)		Sand (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Vazhathope	41.3 ± 6.9	33.0-53.0	18.8 ± 6.4	10.0-30.0	39.9 ± 7.8	22.0-52.0
Kamakshy	38.8 ± 10.4	23.0-63.0	20.8 ± 8.1	10.0-30.0	40.5 ± 9.2	27.0-62.0
Konnathady	37.2 ± 7.3	23.0-48.0	23.3 ± 6.9	15.0-35.0	39.5 ± 8.9	22.0-57.0
Rajakkad	39.7 ± 4.5	33.0-48.0	18.0 ± 5.9	10.0-30.0	42.3 ± 7.9	27.0-57.0
Mariyapuram	43.0 ± 7.4	33.0-53.0	21.9 ± 5.2	10.0-30.0	35.1 ± 8.5	22.0-47.0
Kanjikuzhy	40.7 ± 9.9	28.0-63.0	20.8 ± 7.0	10.0-30.0	38.5 ± 8.8	27.0-52.0
AEU 14	**39.9 ± 8.3**	**23.0-63.0**	**20.8 ± 7.1**	**10.0-35.0**	**39.4 ± 8.6**	**22.0-62.0**

4.2.1.3. Depth of Sand/Silt/Clay Deposition

In Vazhathope panchayath, in regions which faced debris flow, the top soil was washed away by flood. Soil erosion also occurred in many locations. Manysettlements faced mild to severe soil erosion in the panchayath. Sedimentation occurred in the banks of the river in the panchayath. In Vazhathope and Kanjikuzhy panchayaths, there has been deposition of sedimentary sand fractions of soil of about 5 cm depthparticularly in areas along the riverbanks. In Kamakshy, Mariyapuram and Konnathady, sediments were deposited in length and breadth of the land in many points (up to 15 cm depth). In Rajakkad panchayath, due to heavy rain and soil erosion rocky soil got deposited in some agricultural lands (up to 5 cm depth).

4.2.1.4. Soil Moisture and Water Holding Capacity

The soil moisture of soils among different sampling locations ranged from 3.0 to 39.3 per cent with a mean value of 11.4 per cent (Table 9). The highest moisture content was observed in Konnathady panchayath (39.3 %). The soils of Konnathady panchayath had the highest mean value of soil moisture (15.6 %), whereas the soils of

Kanjikuzhy had the lowest mean value of soil moisture content (6.9 %). The other panchayaths Kamakshy, Vazhathope, Mariyapuram, and Rajakkad had mean soil moisture content of 13.3, 11.4, 10.9 and 10.6 respectively.

The water holding capacity of soils among different sampling locations ranged from 29.6 to 62.7 per cent with a mean value of 43.6 (Table 9). The highest water holding capacity (62.7 %) was observed in Kamakshy panchayath. The soils of Mariyapuram panchayath had the highest mean value (46.0 %) for water holding capacity of soil whereas the soils of Konnathady panchayath has the lowest mean value (41.2 %) for water holding capacity of soil. The other panchayaths Vazhathope, Kamakshy, Rajakkad and Kanjikuzhy recorded a mean water holding capacity of 42.8, 41.8, 43.9 and 45.5 respectively.

Table 9. Soil moisture and water holding capacity of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Soil moisture (%)		Water holding capacity (%)	
	Mean ± SD	Range	Mean ± SD	Range
Vazhathope	11.4 ± 9.6	3.2-31.3	42.8 ± 6.4	32.5-53.9
Kamakshy	13.3 ± 9.8	3.2-35.7	41.8 ± 9.2	30.4-62.7
Konnathady	15.6 ± 11.8	3.6-39.3	41.2 ± 7.2	29.6-50.7
Rajakkad	10.6 ± 3.9	6.2-17.5	43.9 ± 5.6	33.6-53.7
Mariyapuram	10.9 ± 3.6	4.7-16.2	46.0 ± 8.2	33.9-57.7
Kanjikuzhy	6.9 ± 2.7	3.0-11.6	45.5 ± 7.4	32.6-61.5
AEU 14	**11.4 ± 7.8**	**3.0-39.3**	**43.6 ± 7.4**	**29.6-62.7**

4.2.1.5. Aggregate Stability

The mean weight diameter (MWD) of soils among different sampling points varied from 0.59 to 2.10 mm with a mean value of 1.23 mm (Table 10). The highest MWD (2.10 mm) was observed in Vazhathope panchayath and also in Rajakkad panchayath. The lowest MWD (0.59 mm) was observed in Konnathady panchayath. The soils of Rajakkad panchayath had the highest mean value (1.35 mm) for mean weight diameter whereas the soils of Vazhathope panchayath had the lowest mean value (1.14 mm) for mean weight diameter. The mean MWD of Kamakshy, Konnathady, Mariyapuram and Kanjikuzhy were 1.22, 1.20, 1.26, and 1.20 mm respectively. The percent water stable aggregates of soils among different sampling points varied from 52.4 to 86.8 per cent with a mean value of 68.9 per cent (Table 10). The soils of Kanjikuzhy panchayath had the highest mean value (69.7 %) of water stable aggregates whereas the soils of Konnathady and Vazhathope recorded the lowest mean value (67.8 %) of water stable aggregates.

Table 10. Aggregate stability of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	MWD (mm)		% of water stable aggregates	
	Mean ± SD	Range	Mean ± SD	Range
Vazhathope	1.14 ± 0.38	0.66-1.83	67.8 ± 5.6	62.0-82.8
Kamakshy	1.22 ± 0.41	0.83-2.10	69.5 ± 5.4	61.0-75.6
Konnathady	1.20 ± 0.41	0.59-1.95	67.8 ± 9.6	52.4-86.2
Rajakkad	1.35 ± 0.44	0.84-2.10	68.7 ± 7.5	56.4-82.0
Mariyapuram	1.26 ± 0.41	0.81-1.97	69.6 ± 7.2	60.8-86.8
Kanjikuzhy	1.20 ± 0.41	0.64-2.00	69.7 ± 5.0	62.4-78.6
AEU 14	**1.23±0.40**	**0.59-2.10**	**68.9±6.7**	**52.4-86.8**

4.2.2. Chemical Attributes of Soil

4.2.2.1. Soil pH, Electrical Conductivity and Organic Carbon Content

Soil pH in the panchayaths varied from 4.66 to 6.49 with the mean value of 5.67 (Table 11). The lowest pH was observed in Rajakkad panchayath (pH 4.66). And the highest pH was observed in Konnathady panchayath (pH 6.49). The soils of Konnathady panchayath recorded the highest mean value for pH (5.78), while the soils of Rajakkad panchayath had the lowest mean value of pH (5.57). Out of total samples, 9 percent of the samples were very strongly acidic (pH 4.5-5.0), 28 per cent of the samples were strongly acidic (pH 5.1-5.5), 37 per cent of the samples were moderately acidic (pH 5.6-6.0) and 26 per cent samples were slightly acidic (pH 6.1-6.5).

Electrical conductivity of the soils in the study area ranged from 0.012 to 0.460 dS m^{-1} with the mean value of 0.125 dS m^{-1}(Table 11). The lowest EC was observed in Vazhathope panchayath (0.012 dS m^{-1}). The highest EC was observed in Rajakkad panchayath (0.460 dS m^{-1}). The soils of Rajakkad panchayath recorded the highest mean value for EC (0.189 dS m^{-1}) while the soils Vazhathope panchayath had the lowest mean value of EC (0.054 dS m^{-1}).

The organic carbon status of soils in the study area ranged from 0.47 to 5.16 per cent with the mean value of 1.97 per cent (Table 11). The soils of Kanjikuzhy panchayath recorded the highest mean value for organic carbon content (2.28 per cent), followed by Mariyapuram (2.22 %). The soils Vazhathope panchayath had the lowest mean value organic carbon content (1.51 %). Among thetotal soils sampled, 70.5 per cent samples recorded high organic carbon (>1.5 %) and 25.6 percent samples recorded medium (0.5-1.5 %). Only 3 samples out of 78 samples were low in organic carbon (< 0.5 %).

Table 11. Soil pH, Electrical conductivity and organic carbon content as influenced by floods in AEU 14 of Idukki district of Kerala

Panchayath	pH		EC (dS m^{-1})		Organic carbon (%)	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Vazhathope	5.71±0.30	5.30-6.28	0.054±0.042	0.012-0.167	1.51±0.65	0.47-2.45
Kamakshy	5.64±0.42	4.94-6.17	0.086±0.056	0.023-0.185	2.03±0.68	0.93-3.15
Konnathady	5.78±0.51	5.01-6.49	0.098±0.064	0.029-0.240	1.65±0.68	0.51-2.64
Rajakkad	5.57±0.61	4.66-6.45	0.189±0.108	0.033-0.460	2.07±0.56	1.16-2.97
Mariyapuram	5.61±0.41	4.97-6.48	0.138±0.097	0.048-0.350	2.22±1.49	0.50-5.16
Kanjikuzhy	5.69±0.50	4.78-6.48	0.166±0.112	0.053-0.430	2.28±0.89	1.04-4.14
AEU 14	**5.67±0.46**	**4.66-6.49**	**0.125±0.096**	**0.012-0.460**	**1.97±0.91**	**0.47-5.16**

4.2.2.2. Available Nitrogen, Phosphorus and Potassium

The available nitrogen content of soils in the six panchayaths varied from 184 to 736 kg ha^{-1} with the mean value of 369 kg ha^{-1} (Table 12). The soils of Kamakshy panchayath recorded the highest mean value for available nitrogen content (428 kg ha^{-1}), followed by Rajakkad (398 kg ha^{-1}). The soils of Vazhathope panchayath had the lowest mean value for available nitrogen content (329 kg ha^{-1}) followed by Mariyapuram (343 kg ha^{-1}).

The available phosphorus content of soils in the six panchayaths varied from 1.5 to 268 kg ha^{-1} with the mean value of 54.9 kg ha^{-1} (Table 12). The soils of Rajakkad panchayath recorded the highest mean value for available phosphorus (67.5 kg ha^{-1}), followed by Konnathady (59.5 kg ha^{-1}) while the soils of Vazhathope panchayath had the lowest mean value for available phosphorus content (41.2 kg ha^{-1}) followed by Kamakshy (49.7 kg ha^{-1}).

The available potassium content of soils in the six panchayaths varied from 11.2 to 784 kg ha^{-1} with the mean value of 307 kg ha^{-1} (Table 12). The soils of Konnathady panchayath recorded the highest mean value for available potassium (396 kg ha^{-1}), followed by Kamakshy (339 kg ha^{-1}), while the soils of Vazhathope panchayath had the lowest mean value for available potassium content (144 kg ha^{-1}).

Table 12. Available nitrogen, phosphorus and potassium status of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Vazhathope	329 ± 108	225-613	41.2 ± 28.0	10.5-99.9	144 ± 123	11.2-426
Kamakshy	428 ± 97	348-654	49.7 ± 31.9	3.9-91.1	339 ± 162	146-650
Konnathady	351 ±136	245-736	59.5 ± 48.0	10.3-171	396 ± 198	146-784
Rajakkad	398 ± 138	245-674	67.5 ± 79.0	2.1-268	329 ± 150	90-627
Mariyapuram	343 ± 124	184-593	55.2 ± 48.3	3.4-155	308 ± 153	112-717
Kanjikuzhy	359 ± 80	245-470	53.8 ± 54.4	1.5-170	318 ± 164	101-560
AEU 14	**369 ± 118**	**184-736**	**54.9 ± 51.3**	**1.5-268**	**307 ± 172**	**11.2-784**

4.2.2.3. Available Calcium, Magnesium, and Sulphur

The available Ca content of soils in the six panchayaths varied from 100 to 1860 mg kg^{-1} with the mean value of 796 mg kg^{-1} (Table 13). The highest available Ca content (1860 mg kg^{-1}) was observed in Mariyapuram. The soils of Rajakkad panchayath recorded the highest mean value for available Ca (1019 mg kg^{-1}), followed by Konnathady (938 mg kg^{-1}), while) the soils of Vazhathope panchayath had the lowest mean value for available Ca content (448 mg kg^{-1}).

The available Mg content of soils in the six panchayaths varied from 24 to 324 mg kg^{-1} with the mean value of 139 mg kg^{-1} (Table 13). The highest available Mg content (324 mg kg^{-1}) was observed in Kamakshy and in Mariyapuram. The soils of Mariyapuram panchayath recorded the highest mean value for available Mg (171 mg kg^{-1}), followed by Kanjikuzhy (154 mg kg^{-1}). The soils of Vazhathope panchayath had the lowest mean value for available Mg content (83 mg kg^{-1}).

The available S content of soils in the six panchayaths varied from 0.5 to 80 mg kg^{-1} with the mean value of 10.1 mg kg^{-1} (Table 13). The highest available S (80 mg kg^{-1}) was observed in Vazhathope and in Konnathady. The soils of Mariyapuram panchayath recorded the highest mean value for available S (13.8 mg kg^{-1}), followed by Vazhathope (11.3 mg kg^{-1}). The soils of Rajakkad and Kanjikuzhy panchayaths had the lowest mean value for available S content (7.8 mg kg^{-1}).

Table 13. Status of available calcium, magnesium and sulphur as influenced by floods in the soils of AEU 14 in Idukki district of Kerala

Panchayath	Available Ca (mg kg^{-1})		Available Mg (mg kg^{-1})		Available S (mg kg^{-1})	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Vazhathope	448 ± 221	140-800	83.0 ± 47.9	24-156	11.3 ± 22.1	0.5-80
Kamakshy	723 ± 40	100-1800	142 ± 80.2	24-324	9.5 ± 15.6	1-60.5
Konnathady	938 ± 469	400-1760	136 ± 47.3	72-204	11.1 ± 21.8	2.5-80
Rajakkad	1019 ± 488	220-1800	146 ± 58.1	48-228	7.8 ± 8.5	1-28.5
Mariyapuram	834 ± 600	240-1860	171 ± 107	48-324	13.8 ± 19.7	1.5-66
Kanjikuzhy	761 ± 354	400-1420	154 ± 71.8	60-300	7.8 ± 10.6	2-41
AEU 14	**796 ± 466**	**100-1860**	**139 ± 74.5**	**24-324**	**10.1 ± 16.5**	**0.5-80**

4.2.2.4. Available Boron

The available B content of soils in the six panchayaths varied from 0.1 to 0.48 mg kg^{-1} with the mean value of 0.2 mg kg^{-1} (Table 14). The highest available boron (0.48 mg kg^{-1}) was observed in Mariyapuram. The soils of Vazhathope panchayath recorded the highest mean value for available B (0.27 mg kg^{-1}), followed by Kamakshy (0.25 mg kg^{-1}), while the soils of Konnathady panchayath had the lowest mean value for available B content (0.14 mg kg^{-1}), followed by Rajakkad (0.17 mg kg^{-1}). Among all the soils sampled, all the samples were deficient in available boron (<0.5 mg kg^{-1}).

Table 14. Available boron status of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Available boron (mg kg^{-1})	
	Mean	Range
Vazhathope	0.27±0.11	0.11-0.46
Kamakshy	0.25±0.07	0.10-0.34
Konnathady	0.14±0.04	0.10-0.27
Rajakkad	0.17±0.08	0.11-0.40
Mariyapuram	0.21±0.11	0.11-0.48
Kanjikuzhy	0.19±0.09	0.10-0.40
AEU 14	**0.20±0.09**	**0.10-0.48**

4.2.3. Biological Attributes of Soil

4.2.3.1. Acid Phosphatase Activity

The acid phosphatase activity of soils in the six panchayaths ranged from 2.2 to 75.2 µg nitrophenol g^{-1} h^{-1} with a mean value of 24.6 µg nitrophenol g^{-1} h^{-1} (Table 15). The highest acid phosphatase activity (75.2 µg nitrophenol g^{-1} h^{-1} was observed in Kanjikuzhy panchayath and lowest acid phosphatase activity was observed in the Vazhathope panchayath. The soils of Rajakkad panchayath recorded the highest mean value (37.9 µg nitrophenol g^{-1} h^{-1}) of acid phosphatase activity, followed by Mariyapuram (25.1 µg nitrophenol g^{-1} h^{-1}). The mean acid phosphatase activity of Vazhathope, Kamakshy, Konnathady, and Kanjikuzhy were 11.3, 19.8, 27.1 and 23.7 µg nitrophenol g^{-1} h^{-1} respectively.

Table 15. Acid phosphatase activity in post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Acid phosphatase activity (μg nitrophenol g^{-1} h^{-1})	
	Mean	Range
Vazhathope	11.3±7.4	2.2-25.1
Kamakshy	19.8±6.1	11.4-33.0
Konnathady	27.1±9.7	10.6-45.0
Rajakkad	37.9±16.1	12.8-65.3
Mariyapuram	25.1±15.8	3.5-49.8
Kanjikuzhy	23.7±17.8	4.5-75.2
AEU 14	**24.6±15.0**	**2.2-75.2**

4.3. SOIL QUALITY INDEX

4.3.1. Formulation of Minimum Data Set (MDS)

Principal Component Analysis (PCA) was used for setting up the minimum data set. All the analysed soil characteristics (21) were considered as vectors for the PCA. The PCA resulted in six principal components (PCs), which had Eigen value more than 1, which was selected for the MDS. The PCs explained 23.3 per cent, 17.4 per cent, 9.0 per cent, 8.7 per cent, 6.1 per cent and 6.0 per cent variance respectively (Table 16).

In the first PC, available calcium, organic carbon acid phosphatase activity, electrical conductivity and available magnesium had high loading factor and hence retained. Second PC consisted of clay per cent. Silt percent was selected from PC3. Available boron and pH was retained from the fourth principal component. In the fifth PC, again pH was retained. Per cent water stable aggregates was the variable retained from the seventh principal component. The final minimum data set selected consisted of ten attributes (Table 17)

Table 16. Result of principal component analysis (PCA)

Particulars	PC1	PC2	PC3	PC4	PC5	PC6
Eigen value	4.196	3.131	1.618	1.570	1.094	1.083
% variance	23.3	17.4	9.0	8.7	6.1	6.0
Cumulative variance	23.3	40.7	49.7	58.4	64.5	70.5
Component matrix						
pH	0.158	0.137	0.043	-0.426	0.548	0.04
EC	0.327	0.209	0.051	0.005	-0.056	-0.061
OC	0.339	0.105	0.14	0.256	-0.167	0.036
N	0.25	0.047	0.2	0.336	0.009	-0.314
P	0.257	0.127	-0.323	-0.026	0.054	-0.004
K	0.273	0.07	0.01	-0.262	0.189	-0.255
Ca	0.35	0.174	0.101	-0.293	0.086	0.063
Mg	0.319	0.102	-0.127	-0.134	-0.146	0.075
S	0.03	0.065	-0.252	0.211	0.444	0.494
B	-0.013	-0.068	-0.034	0.443	0.443	-0.234
Acid phosphatase	0.343	0.141	0.098	0.13	-0.313	0.059
BD	-0.13	-0.082	-0.282	-0.366	-0.306	0.099
WHC	0.175	-0.468	0.065	-0.124	0.068	-0.217
MWD	0.221	-0.383	0.081	0.049	-0.047	0.289
WSA %	0.208	-0.25	0.093	0.128	-0.007	0.562
Clay %	0.144	-0.507	0.007	-0.096	0.051	-0.137
Silt %	0.083	0.165	-0.63	0.175	-0.082	-0.08
Sand %	-0.198	0.338	0.485	-0.047	0.017	0.188

Table 17. Minimum data set (MDS) selected from the entire set of parameters using principal component analysis in the post-flood soils of AEU 14 in Idukki district

PC1	PC2	PC3	PC4	PC5	PC6
Available Ca Organic Carbon Acid phosphatase activity Electrical conductivity Available Mg	Clay %	Silt %	Available B pH	pH	water stable aggregates

4.3.2. Formulation of Soil Quality Index (SQI)

4.3.2.1. Scoring of the Parameters

Organic carbon, acid phosphatase and water stable aggregates obtained highest weightage of 15 followed by pH, Ca, Mg and B of 10 and clay, silt and EC of 5 and these are categorised into four classes with scores ranging from 4 to 1 (Table 18).

4.3.2.2. Computation of SQI and Relative Soil Quality Index (RSQI)

Soil quality index of soil samples ranged from 140 to 325 with a mean value of 266 per cent (Table 19). And the relative soil quality index (RSQI) ranged from 35 to 81.3 per cent with a mean value of 66.6 per cent. The highest mean value of soil quality index (70.2 %) was observed in Rajakkad panchayath whereas the lowest mean value for soil quality index (58.2 %) is observed in Vazhathope panchayath followed by Mariyapuram panchayath (65.3%).

Table 18. Scoring assigned to soil quality indicators of post-flood soils of AEU14 in Idukki district

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
WSA %	15	>90	70 - 90	50 - 70	<50
Texture (clay %)	5	Loam	Clay loam/Sandy loam	Clay/Sand	Grit
Texture (silt %)	5	Loam	Clay loam/Sandy loam	Clay/Sand	Grit
Acid phosphatase (µg nitrophenol g^{-1} h^{-1})	15	>60	30-60	15-30	<15
pH	10	6.5 – 7.5	6 – 6.5	6 – 5.5	<5.5
EC (dS m^{-1})	5	<2	2-4	4-8	>8
Organic carbon (%)	15	>1	1 – 0.75	0.75 – 0.5	<0.5
Available Ca (mg kg^{-1})	10	>300	300 - 250	250 - 150	<150
Available Mg (mg kg^{-1})	10	>120	120-90	90-60	<60
Available B (mg kg^{-1})	10	>15	15 - 10	10 - 5	<5

Table 19. Soil quality index (SQI) and relative soil quality index (RSQI) of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	SQI		RSQI (%)	
	Mean	Range	Mean	Range
Vazhathope	233±44.4	140-305	58.2±11.1	35.0-76.3
Kamakshy	271±26.7	210-310	67.7±6.7	52.5-77.5
Konnathady	273±23.8	240-310	68.3±5.9	60.0-77.5
Rajakkad	281±23.6	245-325	70.2±5.9	61.3-81.3
Mariyapuram	261±32.9	210-300	65.3±8.2	52.5-75.0
Kanjikuzhy	276±27.9	225-320	69.0±7.0	56.3-80.0
AEU 14	**266 ± 33.3**	**140-325**	**66.6±8.3**	**35.0-81.3**

4.4. NUTRIENT INDEX

Computed soil nutrient index of different flood affected panchayaths showed that there is variation in fertility between different panchayaths (Table 20). Nutrient index of organic carbon was medium for Vazhathope panchayath (2.33), high for Kamakshy (2.77), Konnathady (2.67), Rajakkad (2.87), Mariyapuram (2.54) and Kanjikuzhy (2.77) against the nutrient index value <1.67 for low, 1.67 to 2.33 for medium and >2.33 for high fertility status of area.

Nutrient index of available nitrogen was medium for all the panchayaths and the values were 1.75 for Vazhathope, 2.15 for Kamakshy, 1.75 for Konnathady, 1.87 for Rajakkad, 1.92 for Mariyapuram and 1.77 for Kanjikuzhy.

Nutrient index value of available phosphorus was medium for Rajakkad (2.33), and high for all the other panchayaths. And the values were 2.67 for Vazhathope, 2.54 for Kamakshy, 2.67 for Konnathady, 2.54 for Mariyapuram and 2.54 for Kanjikuzhy.

Nutrient index value of available potassium was low for Vazhathope (1.58) whereas high potassium fertility status was observed in other panchayaths, which were 2.62 for Kamakshy, 2.67 for Konnathady, 2.53 for Rajakkad, 2.54 for Mariyapuram and 2.38 for Kanjikuzhy.

4.5. LAND QUALITY INDEX

Land quality index (LQI) of soil samples ranged from 0.77 to 7.91 kg m^{-2} with a mean value of 3.35 kg m^{-2} (Table 21). The highest LQI value (7.91 kg m^{-2}) was observed in Mariyapuram panchayath and the lowest LQI value (0.77 kg m^{-2}) was observed in Vazhathope panchayath. The highest mean value of LQI (3.84 %) was observed in the soils of Kanjikuzhy panchayath whereas the lowest mean value of LQI was observed in Vazhathope panchayath (2.63 %), followed by Konnathady (2.89 %).

Table 20. Nutrient index (NI) of organic carbon and available primary nutrients in post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	Organic carbon		Available N		Available P		Available K	
	NI	Rating	NI	Rating	NI	Rating	NI	Rating
Vazhathope	2.33	Medium	1.75	Medium	2.67	High	1.58	Low
Kamakshy	2.77	High	2.15	Medium	2.54	High	2.62	High
Konnathady	2.67	High	1.75	Medium	2.67	High	2.67	High
Rajakkad	2.87	High	1.87	Medium	2.33	Medium	2.53	High
Mariyapuram	2.54	High	1.92	Medium	2.54	High	2.54	High
Kanjikuzhy	2.77	High	1.77	Medium	2.54	High	2.38	High

Table 21. Soil organic carbon stock and land quality index of post-flood soils of AEU 14 in Idukki district of Kerala

Panchayath	SOC stock ($Mg\ ha^{-1}$)	LQI ($kg\ m^{-2}$)	
		Mean	Range
Vazhathope	7.7-41.1	2.63±1.16	0.77-4.11
Kamakshy	16.0-52.8	3.53±1.08	1.60-5.28
Konnathady	8.7-44.2	2.89±1.08	0.87-4.42
Rajakkad	17.1-46.9	3.43±0.89	1.71-4.69
Mariyapuram	10.7-79.1	3.64±2.33	1.07-7.91
Kanjikuzhy	18.8-71.1	3.84±1.46	1.88-7.11
AEU 14	**7.7-79.1**	**3.35±1.45**	**0.77-7.91**

4.6. CORRELATION STUDIES

Correlation analysis was done to determine the nature and degree of relationship between soil physical properties and organic carbon (Table 22). Bulk density had a significant positive correlation with particle density and a significant negative correlation with organic carbon and porosity. Particle density showed a significant negative correlation with organic carbon. WHC showed a significant positive correlation with per cent clay content of soil. Water stable aggregates (%) had a significant positive correlation with organic carbon content of soil, clay (%) and WHC of soil.

Correlation analysis was done to determine the nature and degree of relationship between soil chemical and biological properties (Table 23). pH had a significant positive correlation with available K and available Ca. Electrical conductivity showed a significant positive correlation with organic carbon, available N, P, K, Ca and Mg. Organic carbon had a significant positive correlation with EC, available N, P, K, Ca and Mg. Available N showed a significant positive correlation with EC, organic carbon, available P and available K. Available P showed a significant positive correlation with EC, organic carbon, available N, available K and available Ca. Available K showed a significant positive correlation with pH, EC, organic carbon, available N, available P, Available Ca, and available Mg. Acid phosphatase activity had a significant positive correlation with EC, organic carbon, available N, P, K, Ca, and Mg.

Table 22. Correlation between soil physical properties and organic carbon of different flood affected panchayaths in AEU 14 of Idukki district

	OC	% Clay	BD	PD	Porosity	WHC	MWD	% water stable aggregates
OC	1.000							
% Clay	0.011	1.000						
BD	-0.363**	0.110	1.000					
PD	-0.489**	0.028	0.279**	1.000				
Porosity	-0.046	-0.068	-0.677**	0.511**	1.000			
WHC	0.078	0.930**	-0.021	-0.044	-0.010	1.000		
MWD	0.130	0.618**	-0.113	-0.191	-0.045	0.576**	1.000	
% water stable aggregates	0.317**	0.351**	-0.039	-0.149	-0.076	0.304**	0.660**	1.000

** Significant at P = 0.01 level, * significant at P = 0.05 level

Table 23. Correlation between soil chemical and biological properties of different flood affected panchayaths in AEU 14 of Idukki district

	pH	EC	OC	Avail N	Avail P	Avail K	Avail Ca	Avail Mg	Avail S	Avail B	Acid phos-phatase
pH	1.000										
EC	0.211	1.000									
OC	0.060	0.501**	1.000								
Avail N	0.026	0.311**	0.431**	1.000							
Avail P	0.214	0.402**	0.252*	0.236*	1.000						
Avail K	0.323**	0.378**	0.251*	0.267*	0.313**	1.000					
Avail Ca	0.545**	0.527**	0.441**	0.195	0.324**	0.433**	1.000				
Avail Mg	0.213	0.444**	0.413**	0.213	0.245*	0.304**	0.610**	1.000			
Avail S	0.024	0.082	0.026	-0.051	0.198	0.019	-0.061	0.045	1.000		
Avail B	-0.090	0.024	0.012	0.180	-0.058	-0.134	-0.148	-0.065	0.112	1.000	
Acid phosphatase	0.036	0.594**	0.562**	0.394**	0.389**	0.282*	0.483**	0.412**	0.040	-0.096	1.000

** Significant at P = 0.01 level, * significant at P = 0.05

Discussion

5. DISCUSSION

The present study was undertaken to assess the soil quality of the severely flood affected areas in AEU 14 of Idukki district and to develop georeferenced maps on soil characterisation. For this purpose, soil samples were collected from six panchayaths of Idukki, Nedumkandam and Adimali blocks of Idukki district and characterised for their physical, chemical and biological attributes. The results of the experiments are discussed in this chapter with supporting studies from literature.

5.1. CHARACTERISATION OF SOIL SAMPLES

Results of physical, chemical and biological attributes of different flood affected panchayaths of AEU 14 in Idukki district are discussed below

5.1.1. Physical Attributes

5.1.1.1. Bulk Density, Particle Density and Porosity

Bulk density is an index of soil workability, availability of moisture, aeration and root penetration. The bulk density of the surface soil ranged from 0.90 to 1.48 Mg m^{-3} with a mean value of 1.16 Mg m^{-3}. Although the individual values varied slightly, bulk density of 73 per cent samples were less than 1.2 Mg m^{-3} (Fig 4). Low bulk density could be due to the influence of organic matter content on soil bulk density which improved the aggregation of soil particles as reported by Tisdall and Oades (2006). There existed a negative correlation between bulk density and organic carbon (Table 22). Gao *et al*. (2019) also observed a negative correlation between soil organic carbon content and bulk density.

Particle density of soil samples in the present study ranged from 1.90 to 2.79 Mg m^{-3} with a mean value of 2.14 Mg m^{-3}. Particle density of 67.9 per cent samples was less than 2.2 Mg m^{-3} (Fig. 5). The particle density of mineral soils typically ranges between 2.6 and 2.8 with an average of 2.65 Mg m^{-3}. Therefore, in the present study the average particle density of soils is much lower than the usual average. Schjonning *et al*. (2017) observed that the particle density of sand and silt particles with low soil organic matter content (< 0.01 kg kg^{-1}) was around 2.65 Mg m^{-3}. If soil organic matter is high, particle density even falls below 2.5 (Donahue, 1961). Ruhlmann *et al.* (2006) observed that the fraction of < 1.6 Mg m^{-3} was characterised by free, non-mineral associated soil organic matter. Particle density decreases within a range of 0.04-0.06 Mg m^{-3} per 1 per cent increase of organic carbon content. These corroborate well with the relatively high organic carbon content (Table 11) and the significant negative correlation obtained between particle density and organic carbon in the present study (Table 22). Hence organic matter rich soils are the reason for lower particle density. Mulching of the plant base with organic materials and tillage might also have led to a lower average density of soil samples.

Pore space is essential for the introduction of air and water in to soil, and for the movement of air, water, nutrients and biota within the soil. The comparatively high organic carbon content and low bulk density observed might have favoured soil aggregation and aggregate stability to a higher degree reducing soil compaction and enhancing soil porosity. This is quite evident from the 50-70 per cent porosity recorded by 25.6 per cent of the samples and 30-50 per cent porosity recorded for 71.8 per cent of the samples analysed in the study (Fig 6). There exists a significant negative correlation between pore space and bulk density. Imparting of a low bulk density, better aggregation, aggregate stability and resultant soil porosity enhances the hydraulic conductivity, nutrient availability and improves soil health (Shah *et al*., 2017).

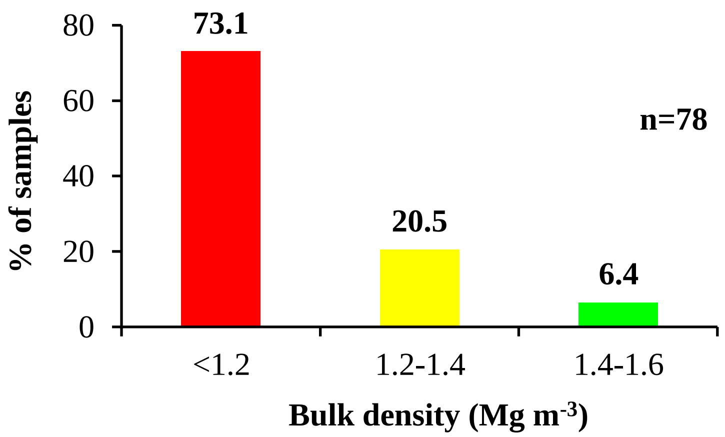

Fig. 4. Frequency distribution of bulk density in post-flood soils of AEU 14 in Idukki district of Kerala

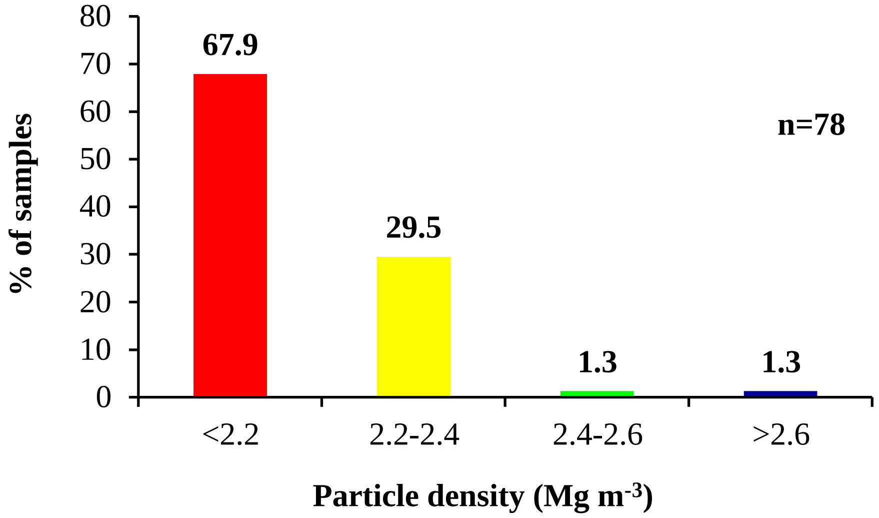

Fig. 5. Frequency distribution of particle density in post-flood soils of AEU 14 in Idukki district of Kerala

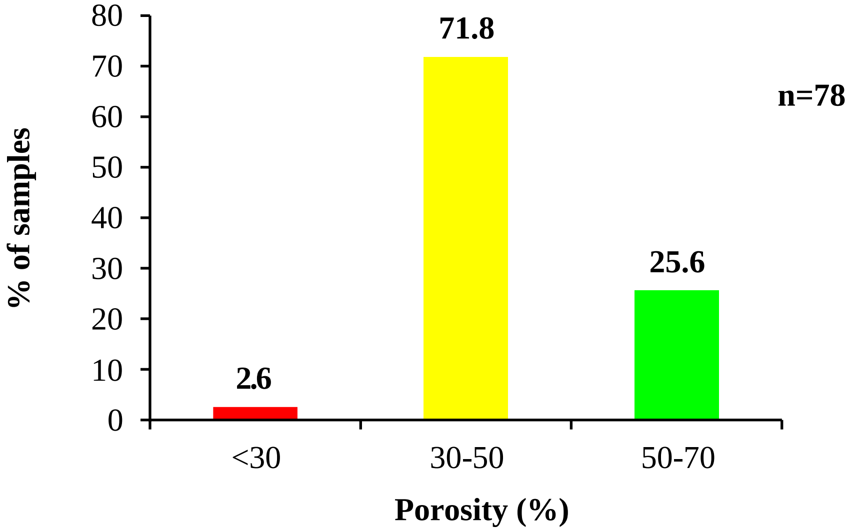

Fig. 5. Frequency distribution of porosity in post-flood soils of AEU 14 in Idukki district of Kerala

5.1.1.2. Particle size distribution

The analyses of particle size distribution show the general picture of the physical nature of the soil and also provide insight into its chemical and biological potentials. Sand, silt and clay are the three standard fractions determining soil texture. In most of the samples, clay and sand contributes the major portion. Silt content was only around 20.8 per cent whereas average clay content and sand content was about 40 percent each. And there was marked variation in texture properties of all soil samples. Thematic map of soil texture is given in Fig. 7. Dominant textural classes in different panchayaths were clay and clay loam (Fig. 8). This is in confirmation with the findings of Anilkumar (2014) who observed that clayey soils were the dominant textural class in Idukki district. The soil texture is an inherent property of the soil amongst the physical attributes. The inherent properties are directly linked to the basic soil forming factors. This attributes show little changes over time (Sharma and Mandal, 2009).

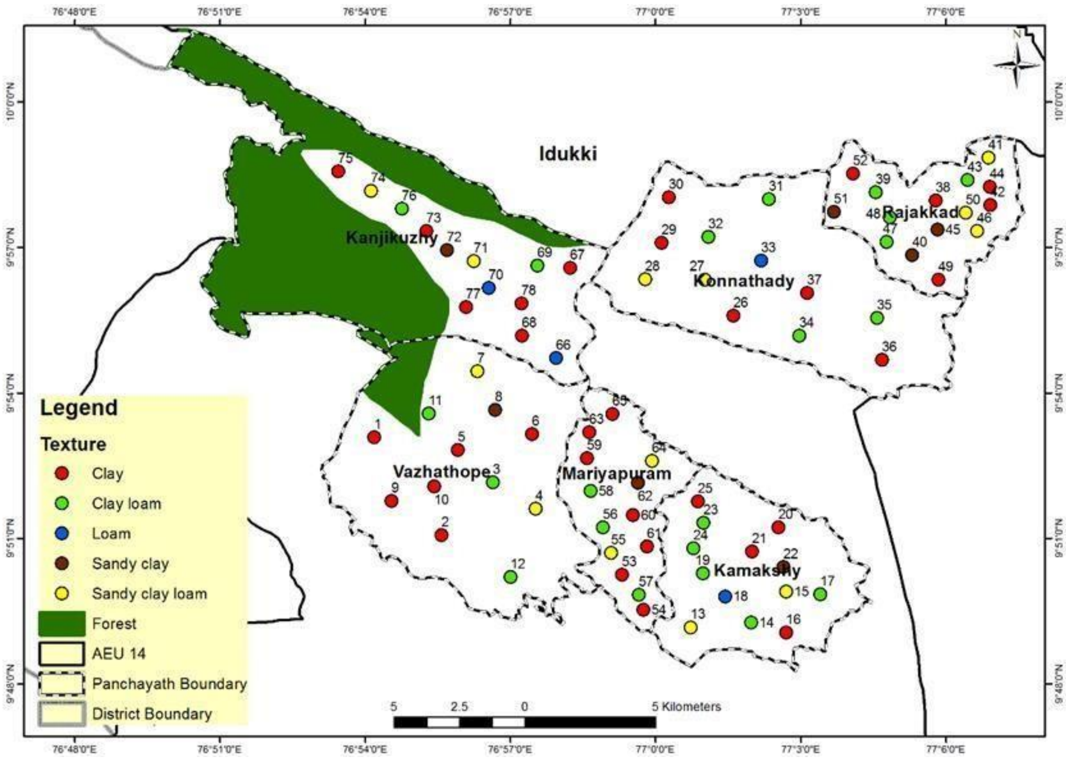

Fig. 7. Spatial variability of particle size distribution in the flood affected panchayaths of the Southern High Hills in Idukki district

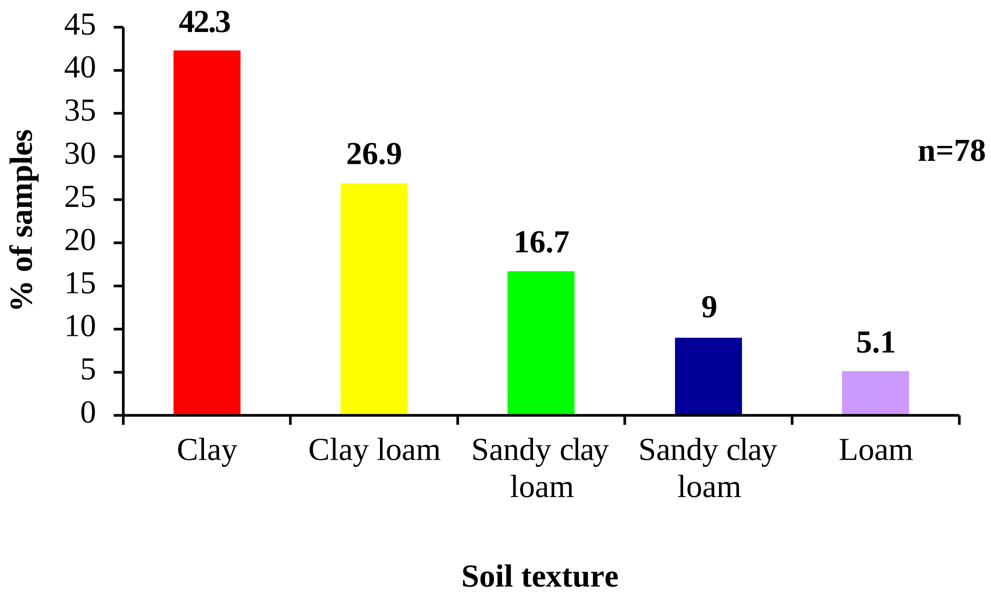

Fig. 8. Frequency of soil textural classes in the post-flood soils of AEU 14 in Idukki district

5.1.1.3. Depth of Sand/Silt/Clay Deposition

Southern High Hills of Kerala (AEU 14) is characterised by hilly terrain and houses two major dams of Kerala; Idukki dam and Cheruthoni dam located in Vazhathope panchayath. Idukki received the highest rainfall (3555 mm over the average 1852 mm) among all districts of Kerala during 2018 flood which resulted in the filling up of dams (Sudheer *et al*., 2019). The water level in the Idukki reservoir, the largest reservoir in Periyar river basin, maintained by three dams, viz. Idukki, Cheruthoni and Kulamavu dams. As water level continued to rise at the Idukki reservoir in Kerala, three shutters of Cheruthoni dam were opened 1.3 m and two shutters 1m to release 750 $m^3 s^{-1}$ or 7,50,000 L s^{-1} (Issac, 2018). The release of this high amount of water from these dams overflowed to the surrounding areas of various panchayaths of AEU 14 for over 10 days. During this river spate, the flood water crossed the bounds of the flood path and started flowing along the ground, depositing the silt materials indiscriminately with a gradual build up of these sediments at various points. The nature of the sedimentation was largely dependent on the type of material the water carried. The 5cm depth of sand bar in Vazhathope and Kanjikuzhy panchayaths has been due to consistent deposition of sedimentary sandy fractions of soil for some reasonable length. Sedimentation of clay and silt particles on the soil surface can affect the ground water recharge at different places in future. Thus, the potential risk of disastrous floods calls for strategic planning by re-establishing the ecological integrity of river ecosystems and making more room for increasing river discharges (Klijn *et al*., 2019).

5.1.1.4. Soil Moisture, Water Holding Capacity and Aggregate Stability

The moisture content of soil samples had a mean value of 11.4 per cent. The moisture content of 55 per cent samples were less than 10 percent (Fig. 9). The average moisture content was almost similar in all panchayaths. Lowest average moisture content in soil was noted in Kanjikuzhy panchayath. The farmers AEU 14 cultivates plantation crops like pepper (65 % farmers), cardamom (45 % farmers), nutmeg (44 % farmers), cocoa (41 % farmers), banana (28 % farmers), coffee (19 % farmers), coconut(17 % farmers) (Table 6). These plantation crops mainly cardamom are sensitive to moisture and temperature. Hence most of the plantations are under irrigation. The soil moisture content in this region was largely influenced by constant irrigation and rainfall during monsoon and post monsoon season. Bindumol and Harilal (2017) reported a moisture content value of 14.62 per cent during post monsoon season in the cardamom growing soils of Idukki district.

Water holding capacity of soils varied from 29.6 to 62.7 per cent with a mean value of 43.6 per cent. Almost 80 per cent of the soil samples had a WHC between 30 to 50 per cent (Fig. 10). The soil textures as well as the organic matter content are considered as the two major factors, those seem to have a profound bearing on the water holding capacity of soils. The water holding capacity of soils has been found to be high in soils with a high clay content which explains the highly significant correlation between clay content and water holding capacity of the soil samples in the present study. Soils with smaller particle sizes have larger surface area and hence are able to retain more water as compared to sand (Bordoloi *et al.,* 2019). It can be mentioned that the moisture retained at a given tension depends on the adsorptive forces of the surface for which clay is the major contributing factor. Shinde (1985) and Anantwar *et al*. (2000) have reported similar results. Shilpa *et al.* (2010) found that water holding capacity of the clayey soils increases under homogenous status of other parameters like organic matter content. It is estimated that an increase of 1 per cent in the soil organic matter content increased the available water holding capacity up to 1.5 per cent times its weight depending on soil texture and clay mineralogy, with a moderate correlation (r= 0.49) for kaolinitic clay (Libohova *et al.*, 2018), the dominant clay mineral type in Kerala soils.

Mean weight diameter recorded from the various locations ranged from 0.59 to 2.10 mm with a mean value of 1.23 mm. MWD of 40 percent samples were less than 1 mm (Fig. 11). The mean weight diameter is a measure of aggregate stability of soil. The aggregate stability depends on the interaction between primary particles and organic constituents to form stable aggregates that are influenced by different factors related to soil environmental conditions and management practices (Amezketa, 1999). Percent of water stable aggregates varied between 52.4 to 86.8 per cent. Frequency distribution of water stable aggregates is given in Fig. 12. The higher aggregation stability might be due to high amount of clay content in the soils (39.9 %). It may have also resulted from the high amount of organic matter content which acts as a cementing agent favouring aggregation. Kelly *et al*. (2017) reported that clay is the most significant granulometric fraction for soil aggregation. The presence of litter and humus in the soil might have contributed towards the higher proportion of water stable aggregates in the soil. Water stable aggregates showed a positive correlation with soil organic carbon. Sanchez (1976) indicated that sodic soils show marked breakdown of aggregates on flooding, whereas soils high in iron and aluminium oxides or organic matter undergo little aggregate destruction. Hence it should be construed that the comparatively higher organic carbon content coupled with the high status of iron and aluminium compounds characteristic of the acidic soils of Kerala might have prevented deflocculation of soil particles subjected to flooding and promoted aggregation.

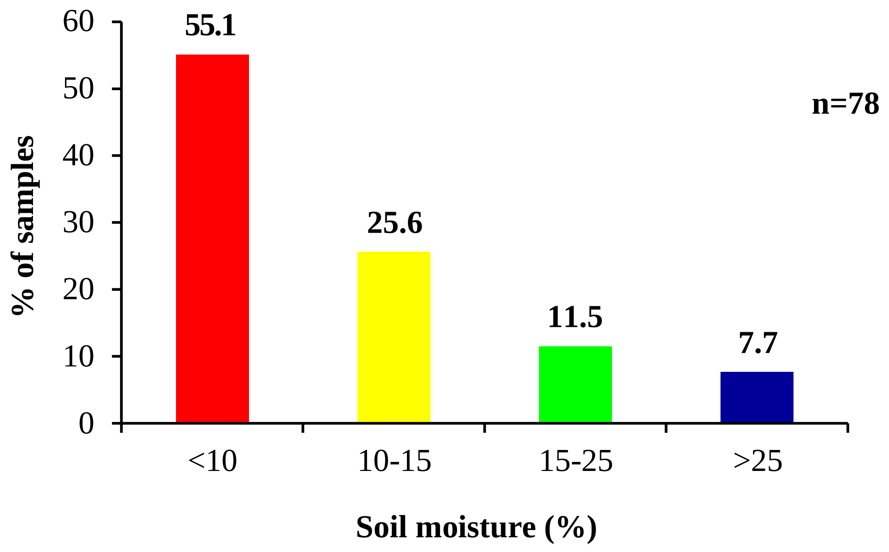

Fig. 9. Frequency distribution of soil moisture content of post-flood soils of AEU 14 in Idukki district of Kerala

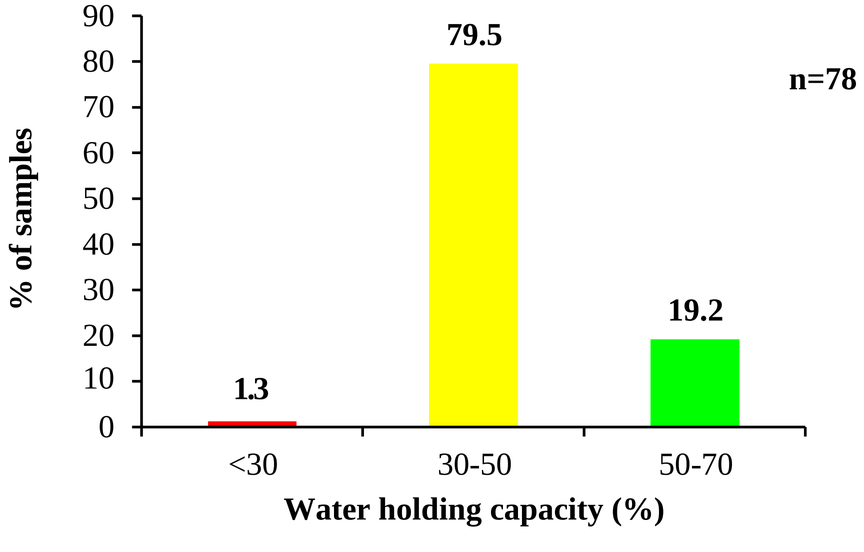

Fig. 10. Frequency distribution of water holding capacity of post-flood soils of AEU 14 in Idukki district of Kerala

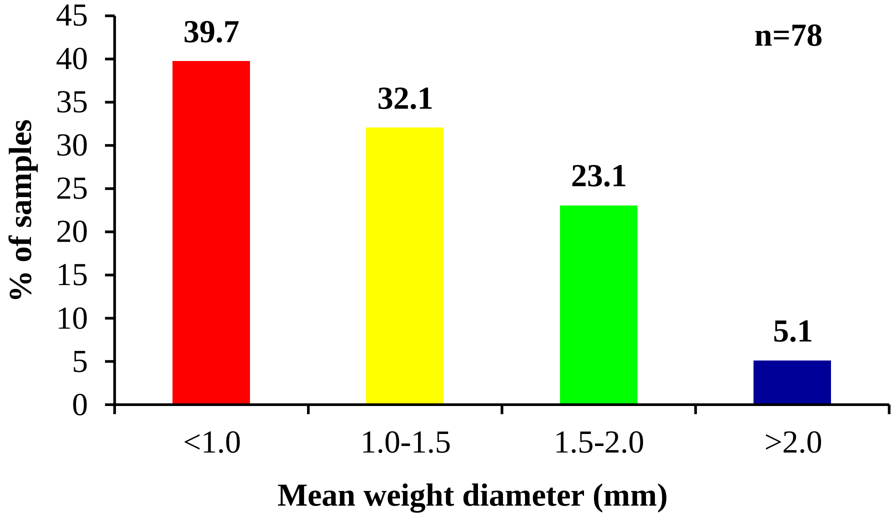

Fig. 11. Frequency distribution of mean weight diameter of post-flood soils of AEU 14 in Idukki district of Kerala

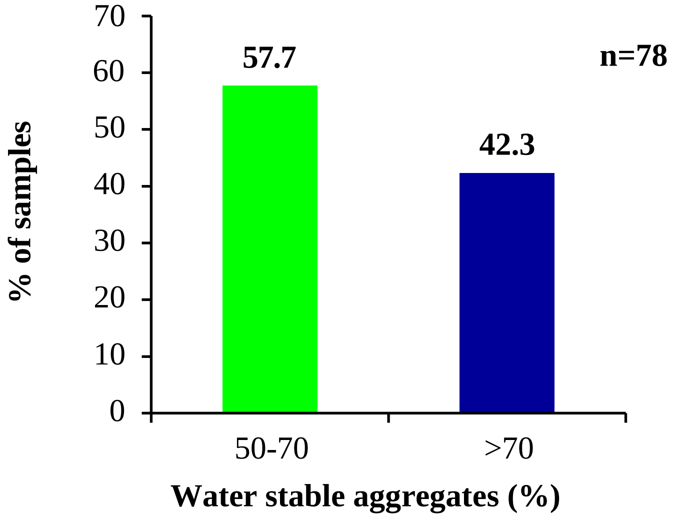

Fig. 12. Frequency distribution of water stable aggregates of post-flood soils of AEU 14 in Idukki district of Kerala

5.1.2. Chemical Attributes

5.1.2.1. Soil Reaction, Electrical Conductivity and Organic Carbon

The mean value of pH in the six panchayaths under study ranged from 5.57 to 5.78. The lowest pH observed among all the soils was 4.66 in Rajakkad panchayath and the highest pH was 6.49 in Konnathady panchayath. The GIS generated thematic map depicting the soil pH status of the sampled area is presented in Fig. 13. It is seen that 37 per cent samples belonged to moderately acid (5.5-6.0), 28 per cent to strongly acid (5.0-5.5), and 26 per cent soils to slightly acid (6.0-6.5) category. Merely 9 percent of the samples were very strongly acidic (Fig. 14). This shows a substantial moderation in the acidic soil reaction with an enhancement in pH as compared to the pre-flood situations where 41 per cent soils were strongly acid (Fig. 15) as reported by Natarajan *et al*. (2013). The variation might have occurred due to the sedimentation of some basic cations at the surface of sampling points. The presence of organic deposits or debris at the surface or its slow degradation must have prevented the production of organic acids and thereby prevented a build-up of acidity at the site. Nair *et al.* (2013) indicated that the soils of Kerala were mostly laterites and basically acidic in reaction.

Soil electrical conductivity is a measure of the dissolved ions in soil. The mean EC values of the six panchayaths varied from 0.054 to 0.189 dS m^{-1}. An inverse relationship between soil pH and EC was quite evident. The highest EC value of 0.189 dS m^{-1} was observed in Rajakkad panchayath which recorded the lowest pH (5.57). The lowest EC observed among all the soils was 0.012 and the highest was 0.460 with a mean value of 0.125 dS m^{-1}. Lowest mean value of EC was recorded in Vazhathope panchayath might be due to heavy leaching of soluble salts by the floodwaters. The low EC indicated that soluble salts were leached out of soil due to high rainfall as reported by Patil *et al*. (2017) and that the prevailing conditions might not be favourable for the accumulation of salts (Roy and Landey, 1962). The unprecedented drastic climatic event exhibiting a deviation of 824 mm of rainfall within a span of two months in July and August 2018 from the mean of the previous ten year period of Idukki district (Table 2) would have caused appreciable leaching of soluble salts. By virtue of the Southern High Hills (AEU 14) of Idukki being located at an elevation of 600 m with characteristic steeply sloping hilly terrain might have facilitated the washing away of soluble salts. The resultant extended submergence owing to flood waters and retention of excessive moisture conditions succeeding the heavy rainfall would have caused an equilibration effect in soil electrochemical properties like pH and electrical conductivity. Ponnamperuma (1984) bears testimony to this flood induced equilibration effect and opines that the flooding of air-dry soils causes direct and indirect electrochemical changes. One direct and almost instantaneous change is dilution of the soil solution which increases pH and decreases electrical conductance as is evident in the present study. However, all the values of electrical conductivity fall within the safe threshold limits (Fig. 16) and therefore, except for a sensitive crop, it is not likely to cause any detrimental effect.

The mean organic carbon values of the six panchayaths varied from 1.51 to 2.28 per cent t. The highest organic carbon content observed among all the soils was 5.16 per cent in Mariyapuram panchayath and the lowest was 0.47 per cent in Vazhathope panchayath with a mean value of 1.97 percent. Spatial distribution of organic carbon is given in Fig. 17. The physiographic location, the agro ecology and the pedogenesis affecting factors pertaining to the Southern High Hills is of particular interest. The AEU 14 comprising of 2,09,695 ha covers 48.06 per cent of the district with a major part under forest cover. Plantations of coconut, pepper, cardamom, cocoa and coffee constitute the cultivated areas. Kanjikuzhy panchayath is enveloped by forest cover in a peninsular manner (Fig. 18). The characteristic physiographic features might have had its bearing on the pedogenesis of the soils of these panchayaths resulting in a high soil organic carbon content in the soils of the unit. Among the total samples, 70.5 per cent of the soil samples were high in organic carbon content in the post-flood soils (Fig. 17), which is an enhancement of over 7 per cent over the previous data pertaining to pre-flood soils, which was only 63 percent (Fig. 19). Higher organic carbon recorded might be due to continuous addition of organic matter through perennial plantation crops. Gupta *et al*. (2010) also reported higher SOC under plantations in the range of 1.50-1.95 per cent . The enhancement in the organic carbon status can also be due to accumulation of organic sources under the influence of flood water. High levels of organic matter enhance nutrient and water retention capacity of soils and create favourable physical, chemical and biological environment (Kavitha and Sujatha, 2015). The high organic carbon content of the soils has resulted in facilitating a centre stage role in enhancing the soil physical, chemical and biological properties in the present study. Physical attributes like bulk density, particle density and water stable aggregates, have largely been benefitted. This is confirmed by the significant negative correlations of the soil organic carbon content with bulk density (r= 0.363**), particle density (r=0.489**) and the significant positive correlation with percentage water stable aggregates (r=0.317**). The significant positive correlation of the soil organic carbon content with all primary nutrients and secondary nutrients Ca and Mg (Table 23) is a further evidence of the primacy of the organic carbon content of soils. The significant positive correlation of the soil organic carbon content with the acid phosphatase activity bears testimony to its ability to serve as a source of energy to the soil microorganisms.

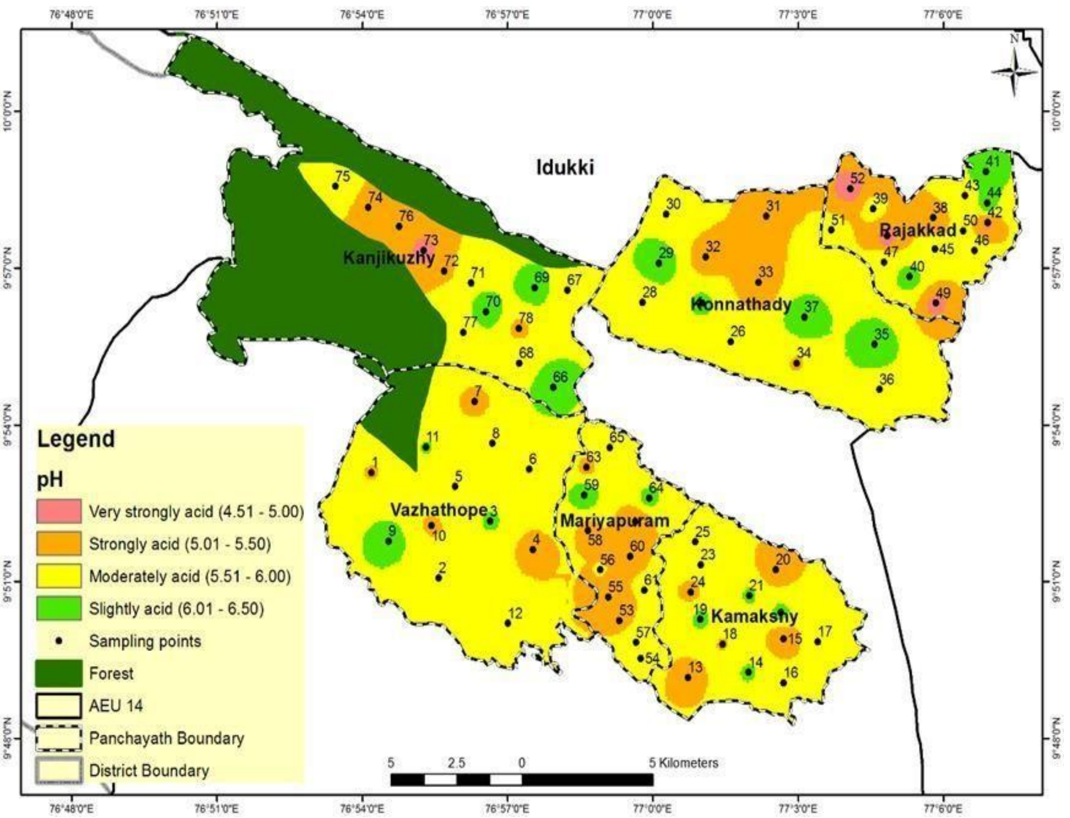

Fig. 13. Thematic map depicting the soil pH of the six flood affected panchayaths of AEU 14 in Idukki district of Kerala

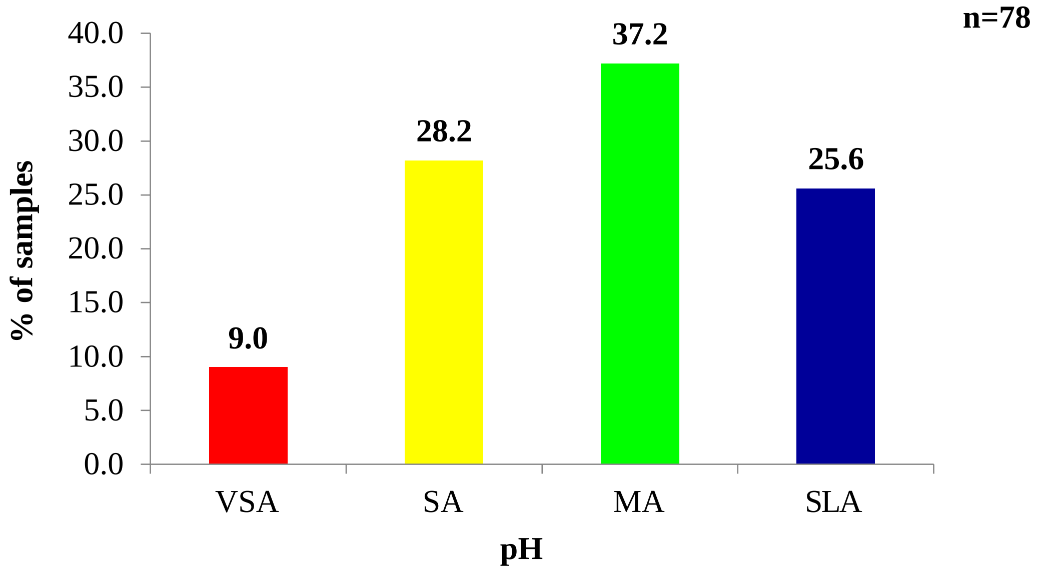

Fig. 14. Frequency of the dominant pH classes in the post-flood soils of the Southern High Hills in Idukki district of Kerala. VSA: Very strongly acidic (4.50-5.00); SA: Strongly acidic (5.00-5.50); MA: Moderately acidic (5.50-6.00); SLA: Slightly acidic (6.00-6.50)

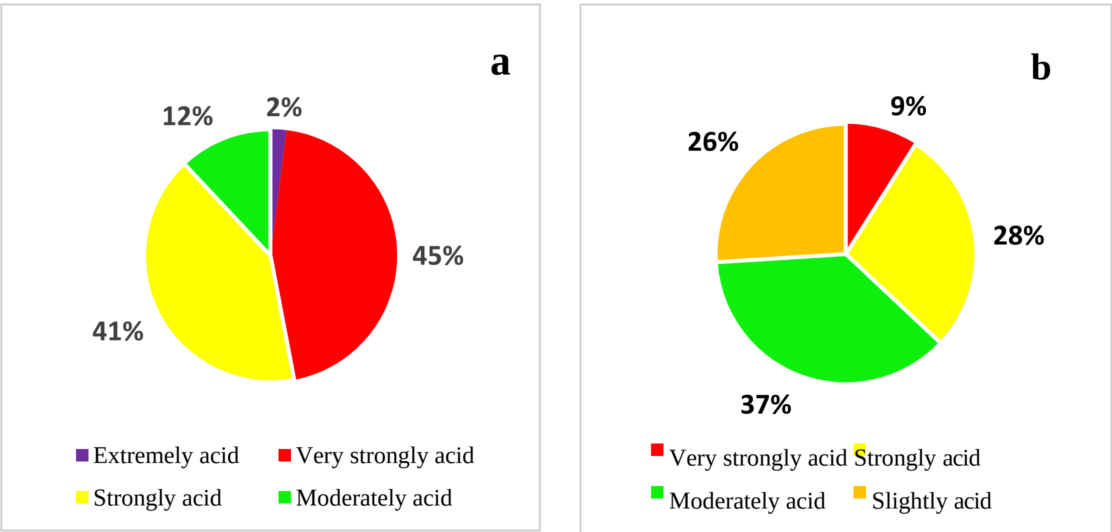

Fig. 15. Comparison of frequency of pH in (a) pre-flood and (b) post-flood soils of AEU 14 in Idukki district of Kerala

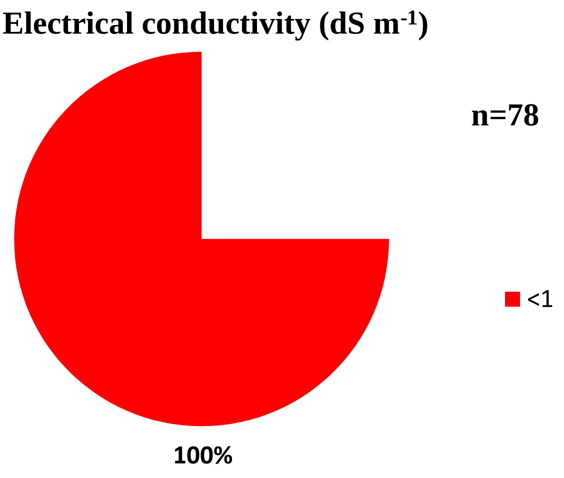

Fig. 16. Frequency distribution of soil electrical conductivity (<1 dS m^{-1}) in the flood affected panchayaths of AEU 14 in Idukki district of Kerala

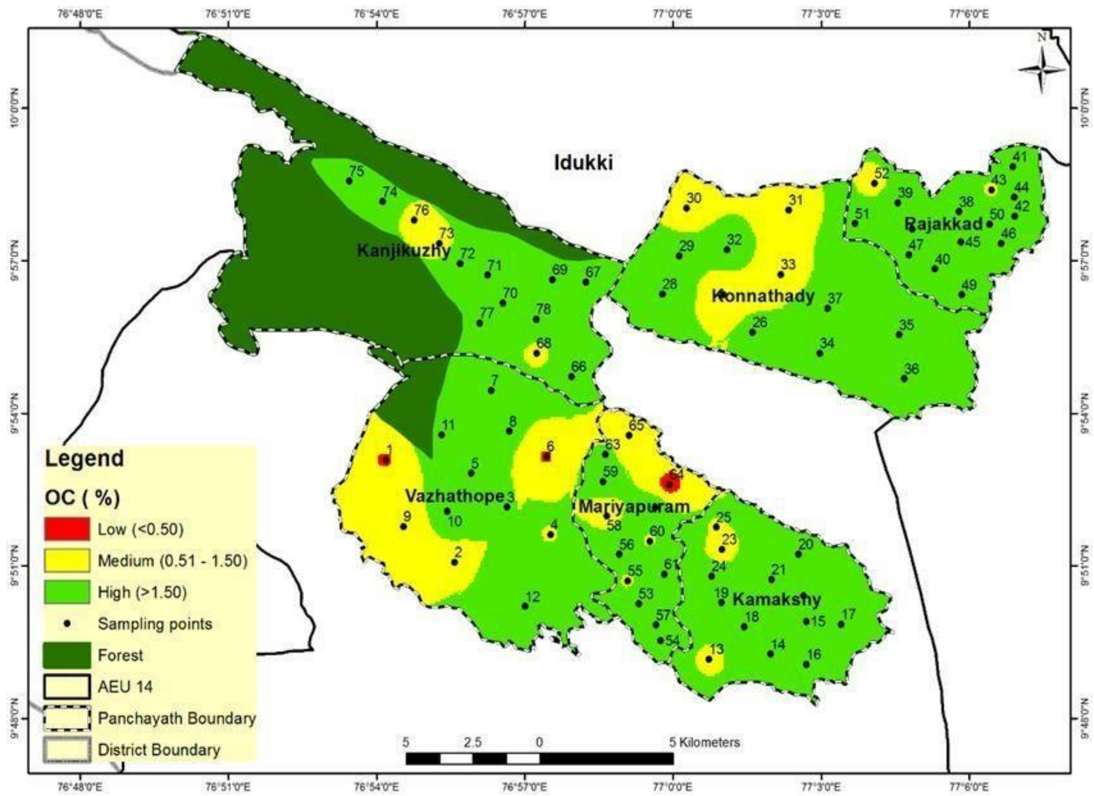

Fig. 17. Spatial variability in soil organic carbon content as affected by floods in the Southern High Hills (AEU 14) in Idukki district of Kerala

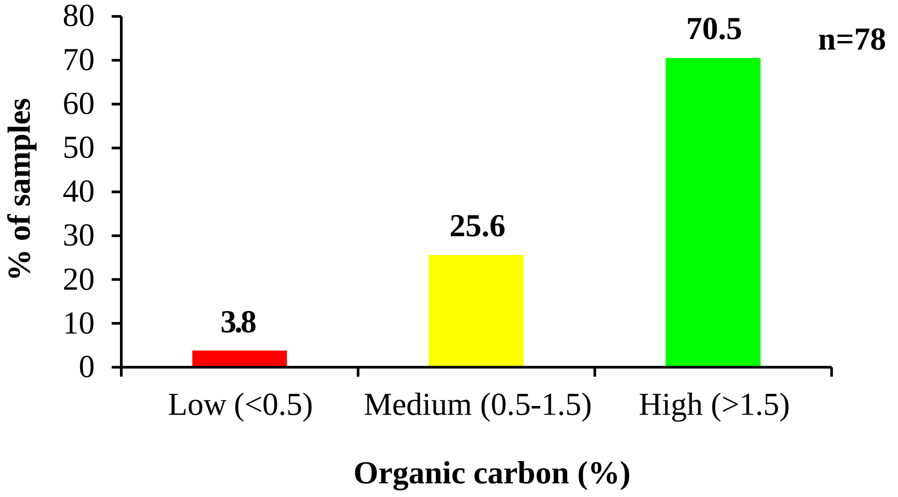

Fig. 18. Frequency of organic carbon classes in the post-flood soils of AEU 14 in Idukki district of Kerala

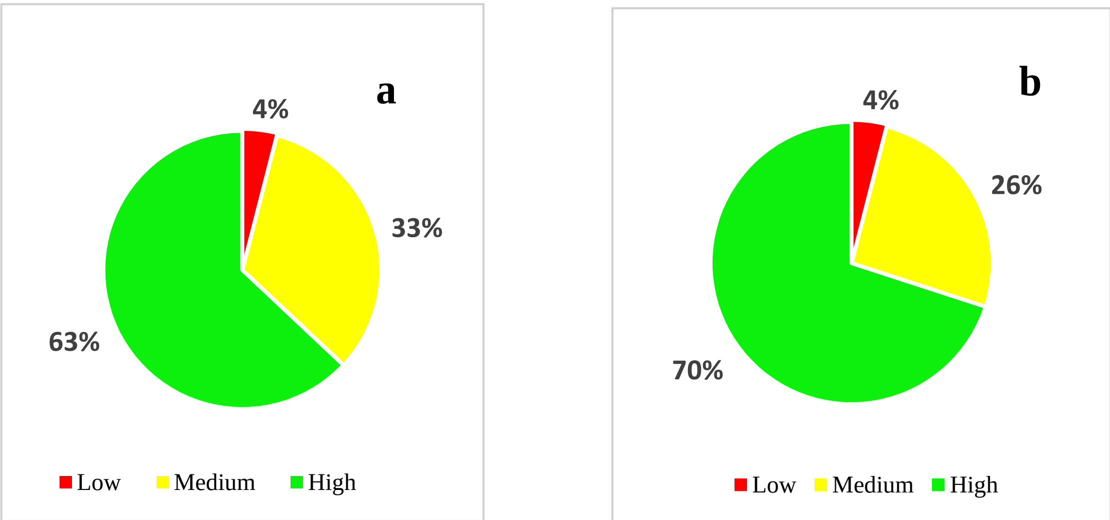

Fig. 19. Comparison of frequency of organic carbon status in (a) pre-flood and (b) post-flood soils of AEU 14 in Idukki district of Kerala

5.1.2.2. Available Nitrogen, Available Phosphorus and Available Potassium

The mean available nitrogen content of soils in the six panchayaths varied from 329 to 428 kg ha^{-1}. The spatial distribution of available N status of the flood affected soils is presented in Fig. 20. Results reveal that the available nitrogen status of the various panchayaths under AEU 14 of Idukki was by and large belonging to the medium category. Majority (67 %) of the soils were medium in available nitrogen content (Fig. 21). The high content of soil organic carbon and predominantly medium status of soil available nitrogen owe their allegiance to the comparatively high soil organic matter content associated with the forest cover, pedogenesis and particular agro ecological considerations. The significant positive correlation ($r=0.431^{**}$) obtained between the soil organic carbon content and available nitrogen status in the soil in the present study reiterates the interrelationship between these two major elements and their dominant role in maintaining fertility and soil health. The dynamics of soil carbon and nitrogen is of prime importance from the soil health point of view in general and the rhizosphere in particular (Jacob, 2018). The organic nitrogen consists of compounds from amino acids, amines, proteins and humic compounds with low nitrogen content. Ammonification is the initial step in the mineralization of organic nitrogen. The optimum pH range for ammonification process is between 6.5 and 7.5 (Li *et al*., 2019). The flooded conditions resulting from the intense rainfall have effected a buffering of pH around neutrality, thus favouring ammonification. Organic soils are known to exhibit highest NO_3^- removal rates owing to a stimulating effect of the peat carbon source on denitrifying bacteria. Moreover, it can be presumed that there was enough carbon to support the heterotrophic processes that utilise the electron acceptors (oxygen, NO_3 and sulphate) available in the infiltrating flood waters (Maliva, 2020). Even with high organic carbon status of the soils under study, medium nitrogen status of the soil may be due to the low mineralization of organic matter as the soils are acidic. Since the study area received high amount of rainfall, low available N in 23 percent of the samples might have resulted due to leaching loss of N in the soils or the absence of nitrogenous materials or organic colloids in the flooded areas from where sampling had taken place. The results are in confirmation with those of Usha and Jose (1983) in laterite soils of Kerala.

Phosphorus is needed for plant nutrition as it is involved in metabolic processes such as photosynthesis, energy transfer and synthesis and breakdown of carbohydrates. The mean value of available phosphorus content of soils in the six panchayaths under study varied from 41.2 to 67.5 kg ha^{-1}. Thematic map of available P in the study area is presented in Fig. 22. Among the total samples analysed, 65 percent of the soil samples were high in available P status and 23 percent soil samples were rated as medium in available P status in the post-flood soils (Fig. 23). On comparison with the pre-flood analytical data, it is observed that there has been an enhancement by one-third in the status of soil available P categorised in the high-class rating (Fig. 24). One of the factors that has a profound bearing on the availability of P in soils is the soil reaction. There exists high variability in the status of plant available P in soils, particularly in the highly weathered acid soils of Kerala. As acidity increases, the enhancement of H^+ ions is complimentarily accompanied by an increase in Fe^{2+} and Al^{3+} ions, which leads to a consequential fixation of the soluble inorganic phosphorus rendering it unavailable. Once sorbed into oxide surfaces, P is capable of being only poorly desorbed, and P retention becomes progressively stronger with time (Yadesa *et al*., 2019). Soil solution and labile P have both been shown to reach a minimum value at pH 5.5 (Edwards, 1991). On the contrary, an increase in pH tending towards neutrality would facilitate the release of the fixed P, thus enhancing the availability in acidic soils. A decrease of 36 per cent in the very strongly acid category and a reduction of 13 per cent in the strongly acid category of pH classes was observed subsequent to flooding. This self liming effect of moderation in soil reaction brought about by flooding might have enabled the increased availability of soil available P in the post-flood soils. The increment in available phosphorus might have also been effected by the different nutrient management practices followed by the farmers. The regular application of phosphatic fertilisers and the immobile nature of phosphate ions in soils might have resulted in accumulation of P in soils (Geurts *et al.,* 2011). The farmers of AEU 14 largely followed integrated nutrient management in their plantation crops, where they regularly applied phosphatic fertilisers along with organic practices like application of bone meal which is yet another rich source of phosphorus. Chelation of phosphorus by organic compounds might have also contributed to the availability. This might have also led to the high P status in the soils of AEU 14. Dinesh *et al.* (2014) reported massive accumulation of P in Kerala soils due to application of high analysis or complex fertilizers resulting in more than 100 kg P ha^{-1} in more than 62 per cent of soil samples analysed across the state. Another possible reason could be the mineralisation of organic matter deposited at the surface soil during flood. Thus the fertilizer doses for the soils can be reduced by analysing site specific high and very high nutrient availability in soils which will help to reduce the cost of cultivation in addition to ensuring a balanced supply of nutrients. It is therefore necessary to encourage the use of lime and fertilisers based on soil test recommendations in Idukki district to help farmers use expensive P fertilisers sensibly and prudently.

Though potassium in soils exist as water soluble, exchangeable, fixed and lattice bound forms, the available potassium in soil largely comprises of the water soluble and exchangeable fractions. In the medium range of availability, the available potassium values vary from 115 to 275 Kg ha^{-1}. Spatial distribution of available K is presented in Fig. 25. Among the total soils sampled, 53.8 per cent samples were rated to be high in available potassium, and 32.1 per cent samples were in medium range (Fig. 26) whereas in the pre-flood soils, it was 45 and 35 per cent respectively (Fig. 27). The flood induced availability of soil potassium increased by about 8 per cent in comparison with the pre-flood soil availability. The mean value of available potassium content in the soils in the six panchayaths varied from 144 to 396 kg ha^{-1}. The panchayaths were generally high in available potassium. Similar results were obtained by Natarajan *et al.* (2013). Losses of potassium depend largely on the soil K-holding capacity, which to a considerable extent is determined by the soil texture and soil mineralogy. The flood ravaged soils of AEU 14 were observed to be predominantly belonging to the clayey (42.3 %) and clay loam (26.9) textural classes. Tropical soils have a predominance of low activity clays such as kaolinite and iron and aluminium oxides and hydroxides. Tropical clay soil can store K, even without a large content of high activity clays, and so avoid losses by leaching (Rosolem and Steiner, 2017). Hence it may be construed that the low activity clay minerals in the clay and clay loam soils of the Southern High Hills of Idukki were efficient in holding the exchangeable potassium to a considerable extent. Vazhathope panchayath alone had a low mean value of available potassium which could be attributed to heavy leaching by the flash flood. Johnston and Goulding (1992) suggested that approximately 1.0 kg ha^{-1} of K is lost for every 100 mm of rainwater leached through the soil in a field. Soil organic matter play an important role in the K status of soils. Despite heavy rainfall and consequent leaching, the high available K content in some panchayaths could be attributed to accumulation of organic carbon sources and its mineralisation or the availability of potassium bearing sediments at the sampling sites in the post flood situation. Tan *et al*. (2017) in his results showed that long-term continuous potash application significantly reduced soil K fixation capacity and thus optimise available K in the soil. This might be another reason for high K status observed in the soil.

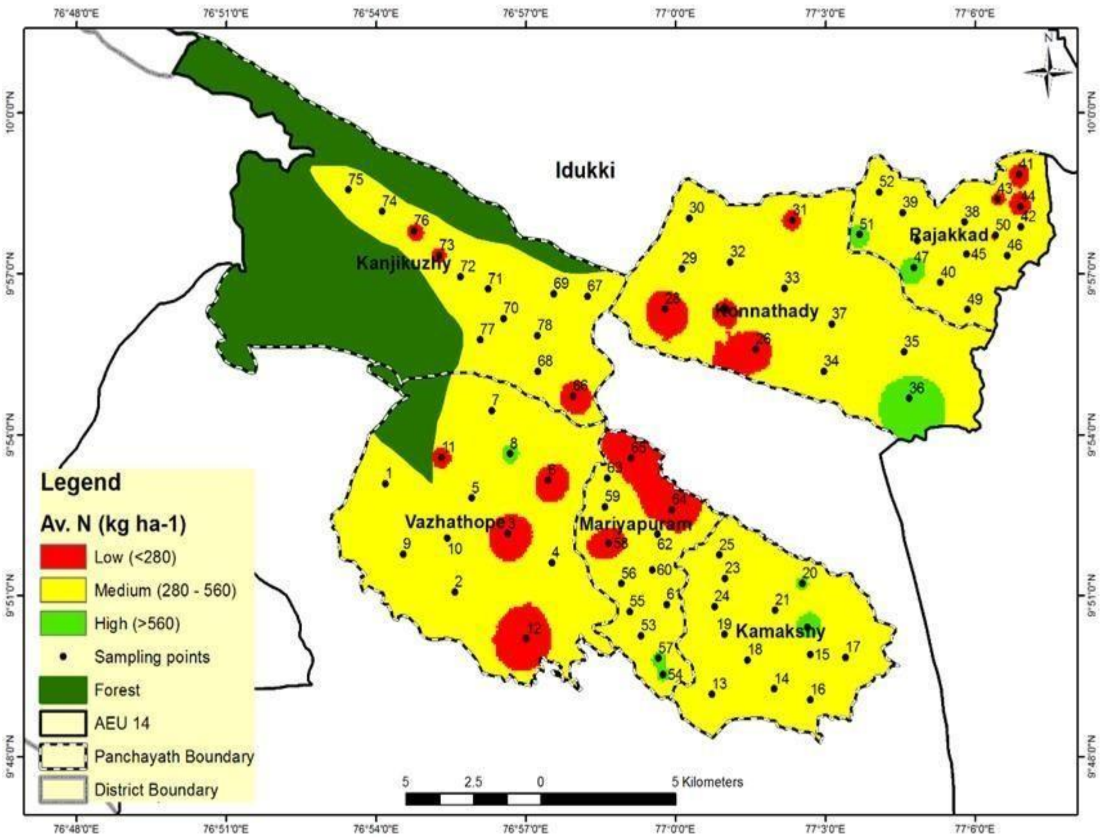

Fig. 20. Spatial distribution of available N of post-flood soils of AEU 14 in Idukki district of Kerala

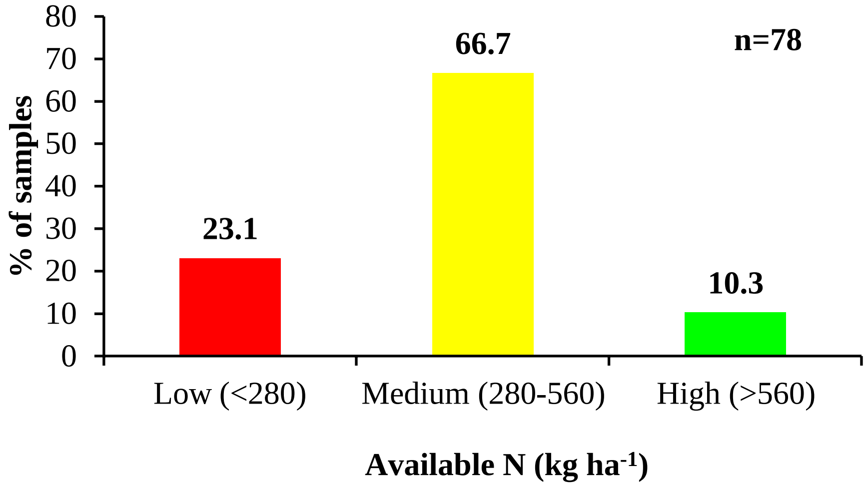

Fig. 21. Frequency of available N classes as affected by floods in the soils of AEU 14 in Idukki district of Kerala

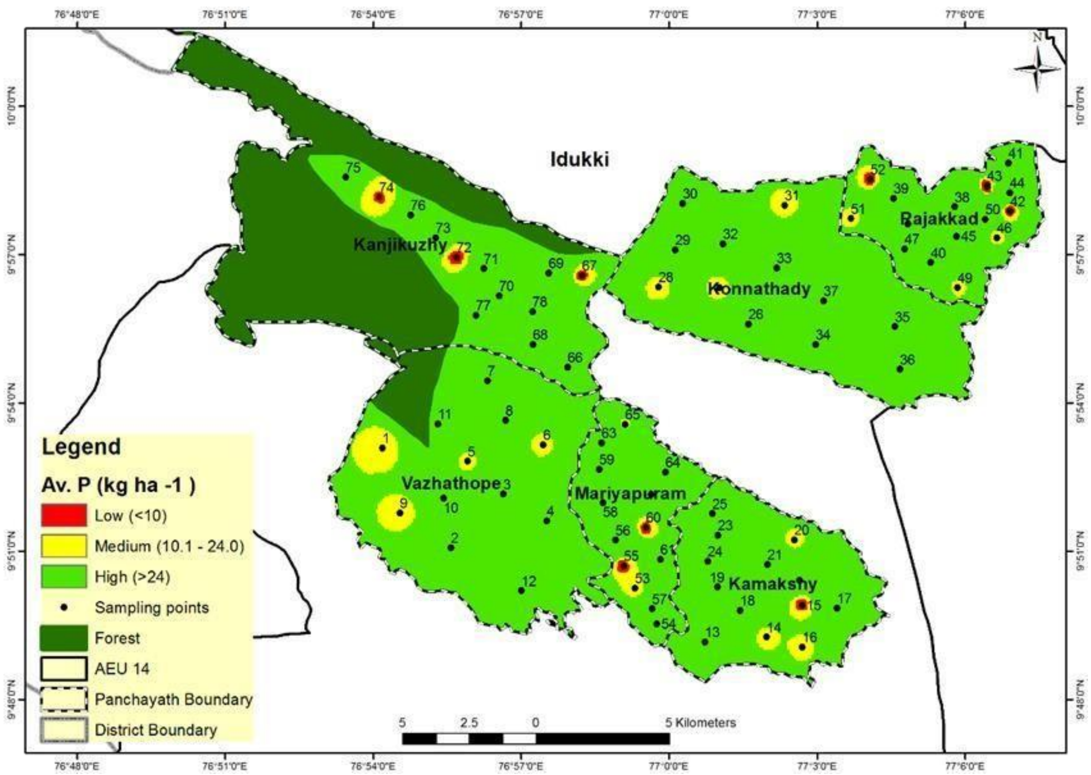

Fig. 22. Spatial variability of available P of post-flood soils of AEU 14 in Idukki district of Kerala

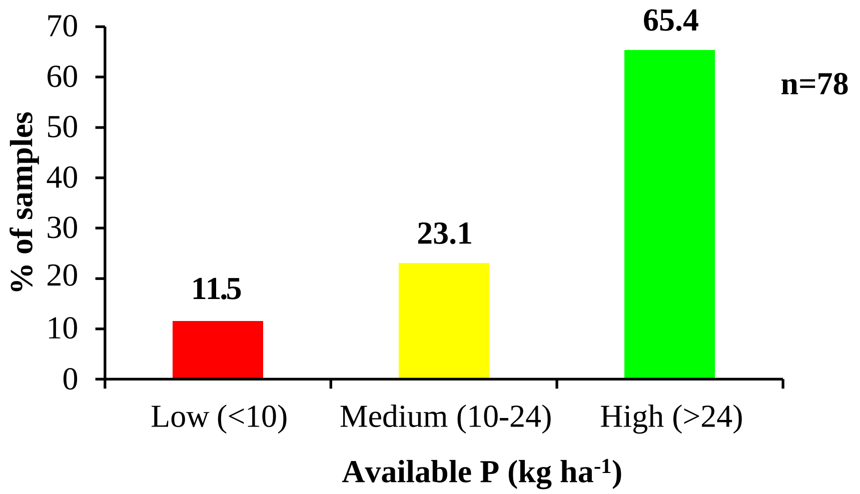

Fig. 23. Frequency distribution of available P of post-flood soils of AEU 14 in Idukki district of Kerala

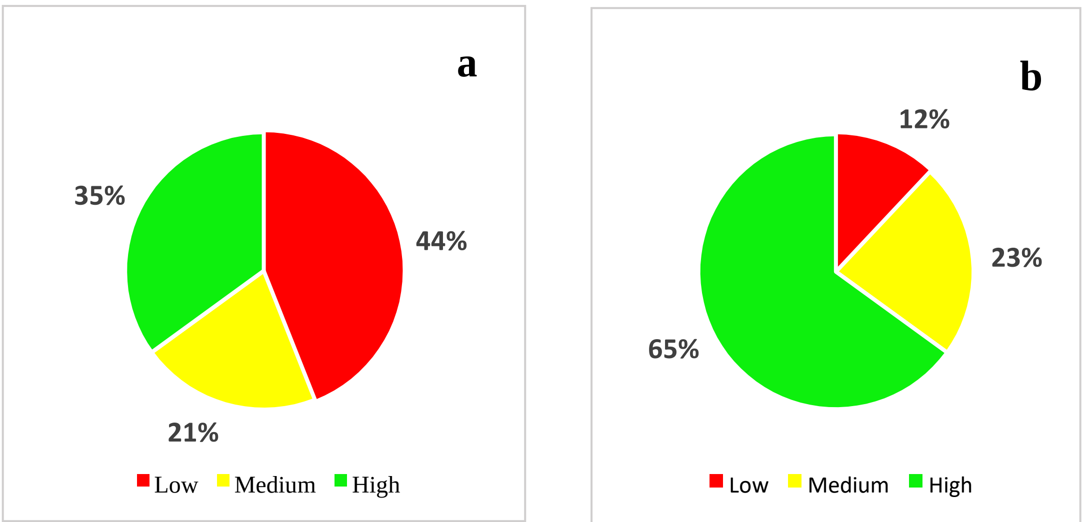

Fig. 24. Frequency available P classes of (a) pre-flood soils in comparison with (b) post-flood soils of AEU 14 in Idukki district of Kerala

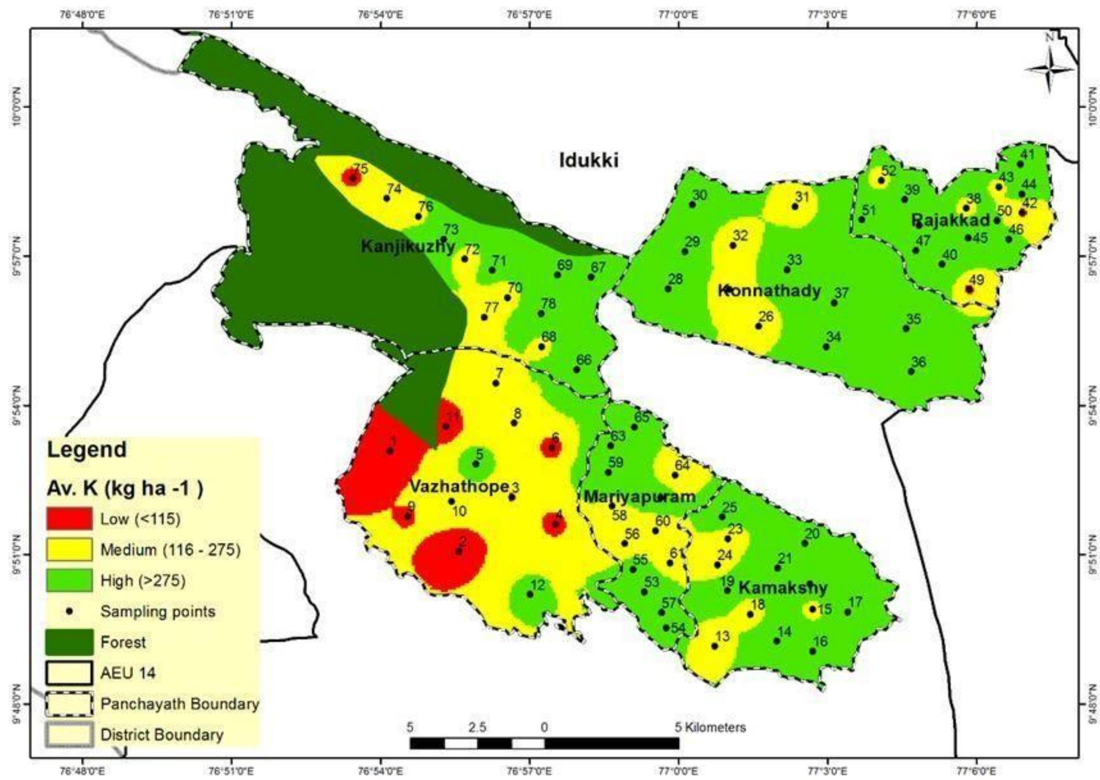

Fig. 25. Spatial variability of soil available K as influenced by floods in AEU 14 of Idukki district of Kerala

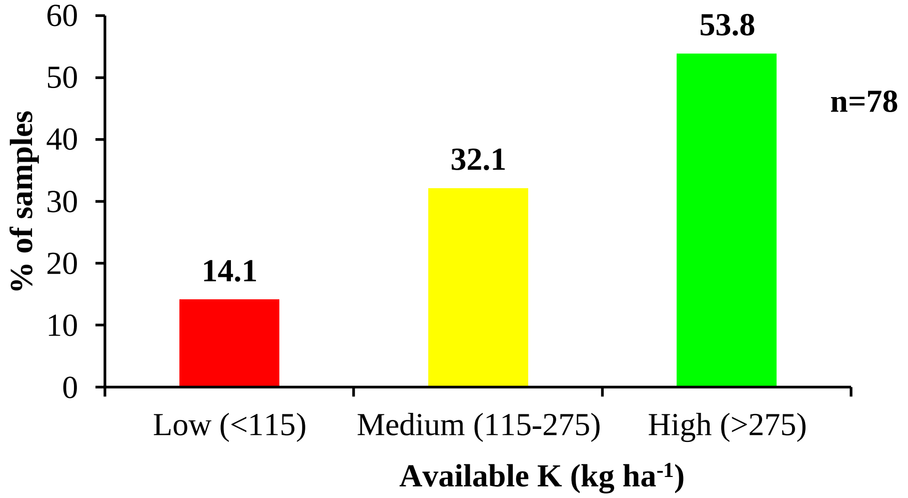

Fig. 26. Frequency of available K classes of post-flood soils of AEU 14 in Idukki district of Kerala

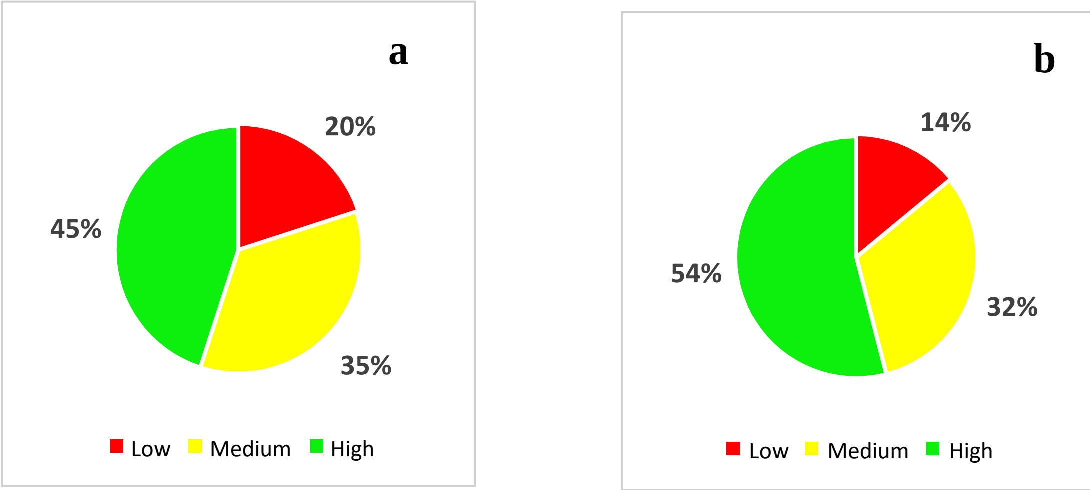

Fig. 27. Comparison of frequency of available potassium status in (a) pre-flood and (b) post-flood soils of AEU 14 in Idukki district of Kerala

5.1.2.3. Available Calcium, Available Magnesium and Available Sulphur

The mean value of available calcium content of soils in the six panchayaths varied from 448 to 1019 mg kg^{-1}. Majority of the soils were adequate in available calcium (Fig. 28). Ideally, for healthy and productive soil, the concentration of calcium should be around 300 mg kg^{-1}. Among the total soils sampled, 89.7 per cent samples were adequate in available calcium (Fig. 29) whereas in the pre-flood soils, it was 74 percent (Fig 30). Similar trend of high calcium was obtained in Idukki district by Natarajan *et al*. (2013). The plantation crops like coffee and cardamom are sensitive to aluminium and manganese toxicity. In such conditions, liming is required. So the farmers of AEU 14 of Idukki district who are mainly plantation growers follow liming in order to raise the pH and alleviate aluminium and manganese toxicity. Liming might have led to the increase in Ca content of the soil. An increase in the amount of available calcium in the post-flood soils could be possibly from the deposits carrying basic cations after the flood. A high mean value of available Ca in Rajakkad panchayath (1019 mg kg^{-1}) might be due to flow of basic cations by the flood water downhill through the slopy terrain and deposition in the valley areas of agricultural lands under vegetables and paddy. Magnesium is absorbed by plants from the soil solution as Mg^{2+} ion. The magnesium concentration of 120 mg kg^{-1} is considered sufficient in soil for crop production. The mean value of available magnesium content of soils in the six panchayaths varied from 83 to 171 mg kg^{-1}. Spatial distribution of available Mg is given in Fig. 31. Among the total soils sampled, 51.3 per cent of the soil samples were adequate in available magnesium (Fig. 32) whereas in the pre-flood soils only 18 per cent soils were adequate (Fig. 33). A build up in the amount of available magnesium in the soil possibly from the deposits carrying basic cations after the flood along with calcium might be the reason for a reduction in the magnesium deficiency in the post flood soils of AEU 14. Bhayo *et al*. (2018) observed a similar trend of increase in available Ca and Mg in the post-flood soils in Jacobabad district in Pakistan where the Ca and Mg levels has been increased from low to optimum level compared to the pre-flood data. However, magnesium, being a weak competitor for exchange sites with aluminium and calcium, appears to accumulate in solution phase and is subject to leaching loss in acid soils (Edmeades *et al*., 1985) which might be the reason for lower magnesium in many sampling points despite of the high calcium content there.

Sulphur is mostly present in soil as sulphides, sulphates and organic fractions associated with nitrogen and carbon. They must be converted to the sulphate (SO_4^{2-}) form to be absorbed by the crop. This conversion is mediated by soil microbes and therefore all soil conditions must be favourable for the existence of microbes. The mean value of available sulphur in the six panchayaths varied from 7.8 to 14.3. Thematic map of available S is given in Fig. 34. About 49 per cent samples were deficient in available sulphur and 51 per cent samples were adequate (Fig. 35) whereas in the pre-flood soils, 82 per cent soils were deficient and 18 per cent soils were adequate (Fig. 36). There has been a reduction in the deficiency of sulphur in the post-flood soils. Addition of either lime or phosphate decrease the adsorption of inorganic sulphate by increasing the net negative charge of the soil and increase the mineralization of organic S either by increasing the microbial activity or by chemical hydrolysis. The combined effects of decreased adsorption and increased mineralization produce an increase in $CaCl_2$ extractable sulphate. After liming an acid soil, Serrano *et al*. (1999) observed an increase in SO_4 concentration in the soil solution. Bolan *et al.* (1988) observed that sulphate released from sparingly soluble iron and aluminium hydroxy sulphates which becomes more soluble at higher pH. Biswas *et al.* (2003) also observed similar results. So the increase in available sulphur in the soils might be due to increase in pH of the post-flood soils. Thus it has been suggested that both liming and phosphate addition increases the availability of sulphate to plants. A reduction in the sulphur deficiency in the region might be also due to an integral effect of wide spread use of factomphos, a complex NP fertiliser by the farmers. Deficiency of sulphur in certain places can be due to low pH and low content of sulphur bearing minerals (Ananthanarayana *et al.*, 1986).

5.1.2.4. Available Boron

Boron is an essential non-metal micronutrient element required for the normal growth of plants. The mean value of available boron in the six panchayaths varied from 0.14 to 0.27 mg kg^{-1}. The highest available boron observed was 0.48 mg kg^{-1} and the lowest was 0.10 mg kg^{-1}. All the panchayaths were deficient in available B (Fig. 37). Similar results were obtained by Mini and Mathew (2015). Rajasekharan *et al.* (2014) reported that the deficiency of available boron in soils of Kerala was acute and extensive where they observed that nearly 60 per cent of the samples were B deficient all over Kerala and found that the acid leaching environment of Kerala soils is not conducive for retention of this nutrient. Singh (2009) stated that deficiency of B is a major impediment in acid soils, the soils of Meghalaya, Assam and West Bengal which show several similarities in agro-ecological aspects with that of Kerala suffer the same in a severe degree. All the samples collected from the post-flood soils were deficient in available B (Fig. 38) whereas in the pre-flood data, 86 per cent soils were deficient (Fig. 39). An increase in the deficiency of available B in post-flood soils of AEU 14 might be due to leaching by high rainfall (Bhandari and Randhava, 1985). Extensive leaching of this ion from the surface soils during floods might have pushed down the available boron status in the soil. Managing B is difficult because of its high mobility especially in the soils of hilly regions. Application of borax or foliar spray of borax solution can supply available boron in such soils.

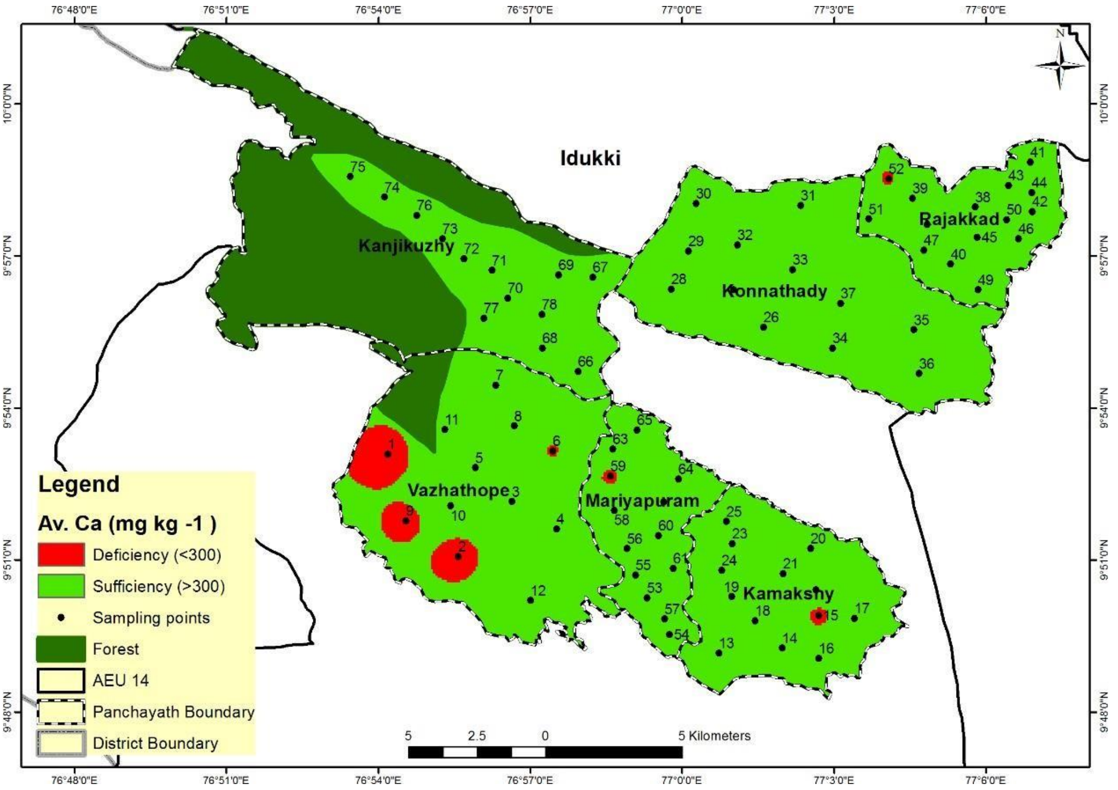

Fig. 28. Spatial distribution of available Ca of post-flood soils of AEU 14 in Idukki district of Kerala

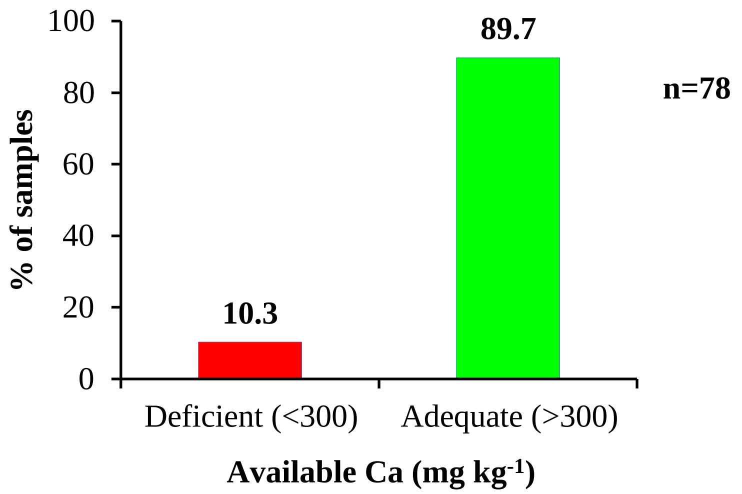

Fig. 29. Frequency distribution of available Ca of post-flood soils of AEU 14 in Idukki district of Kerala

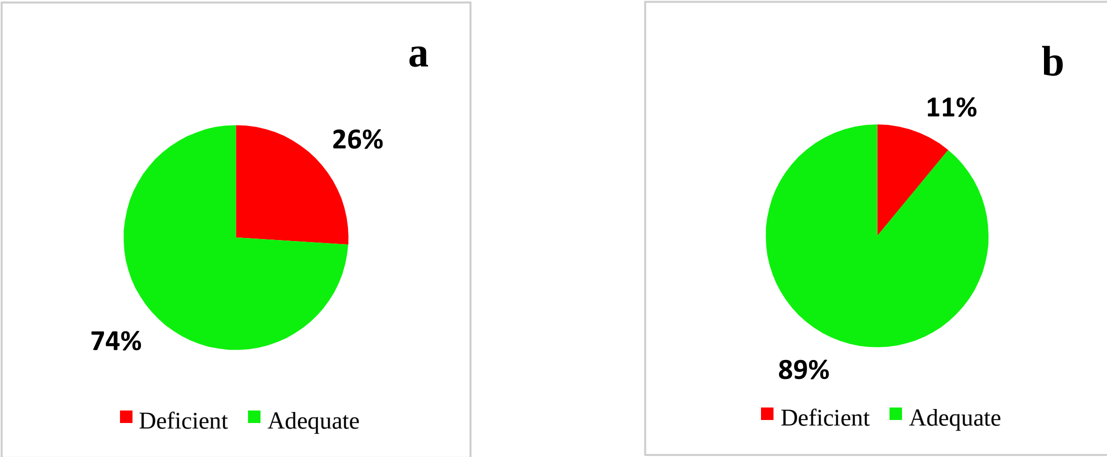

Fig. 30. Frequency of available calcium classes of (a) pre-flood soils in comparison with (b) post-flood soils of AEU 14 in Idukki district of Kerala

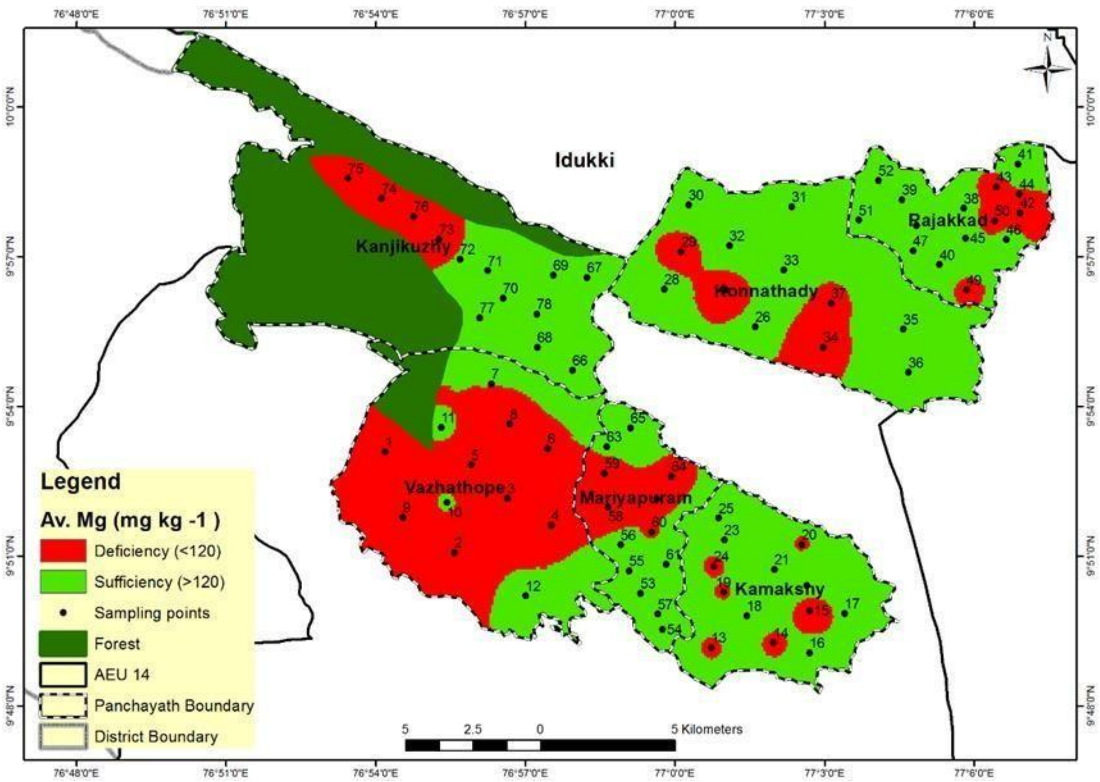

Fig. 31. Spatial distribution of available Mg of post-flood soils of AEU 14 in Idukki district of Kerala

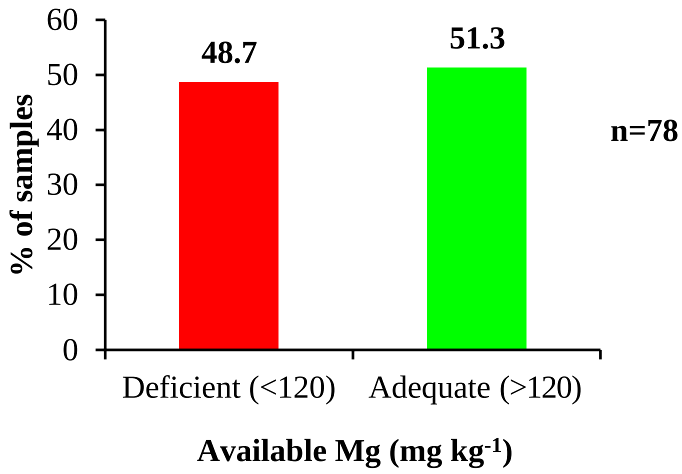

Fig. 32. Frequency distribution of available Mg of post-flood soils of AEU 14 in Idukki district of Kerala

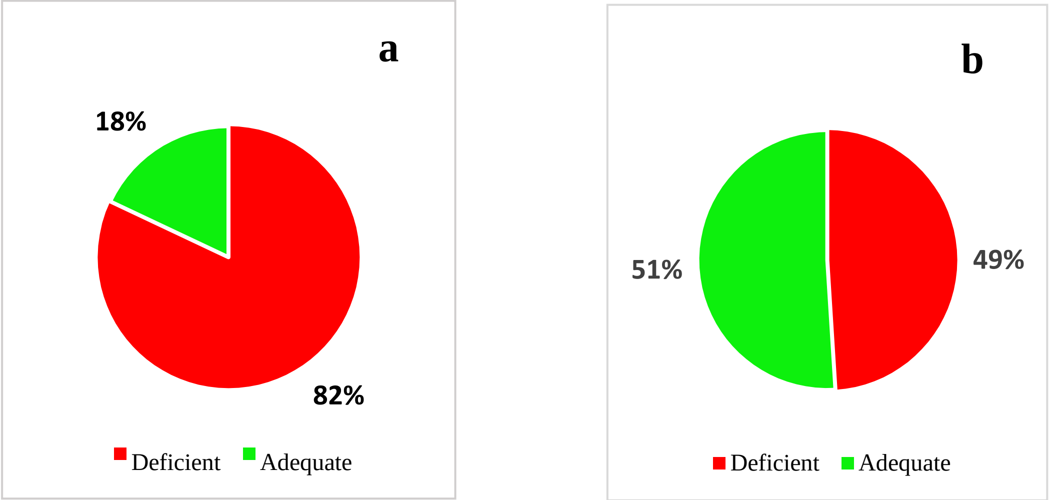

Fig. 33. Comparison of frequency of available magnesium status in (a) pre-flood and (b) post-flood soils of AEU 14 in Idukki district of Kerala

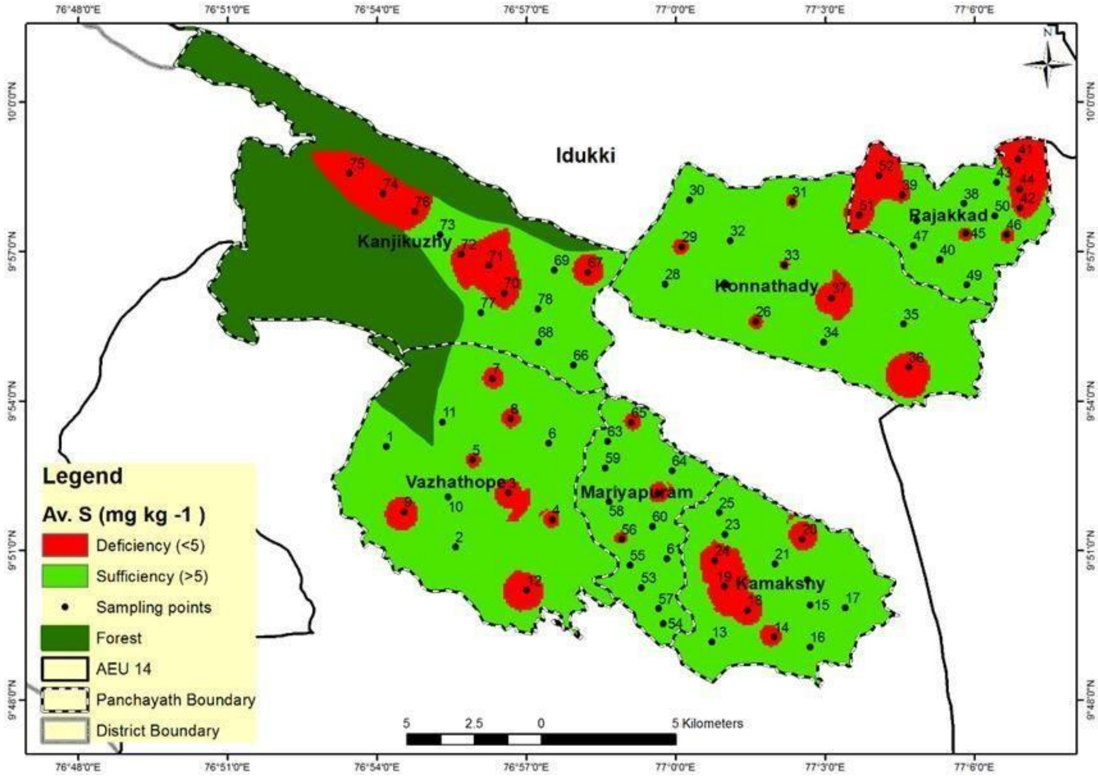

Fig. 34. Spatial distribution of available S of post-flood soils of AEU 14 in Idukki district of Kerala

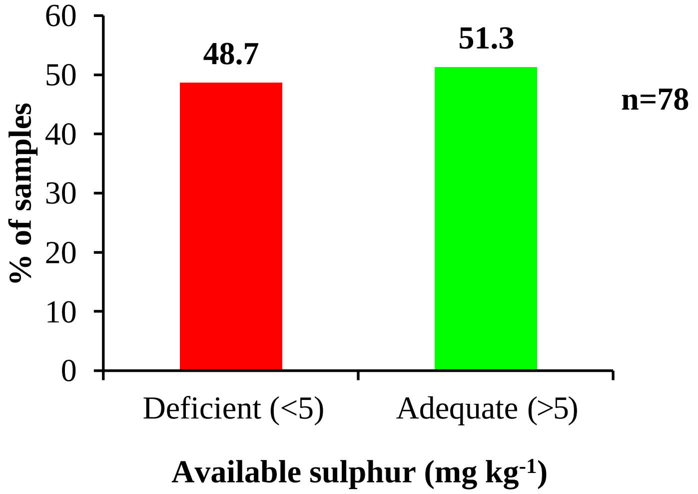

Fig. 35. Frequency distribution of available S of post-flood soils of AEU 14 in Idukki district of Kerala

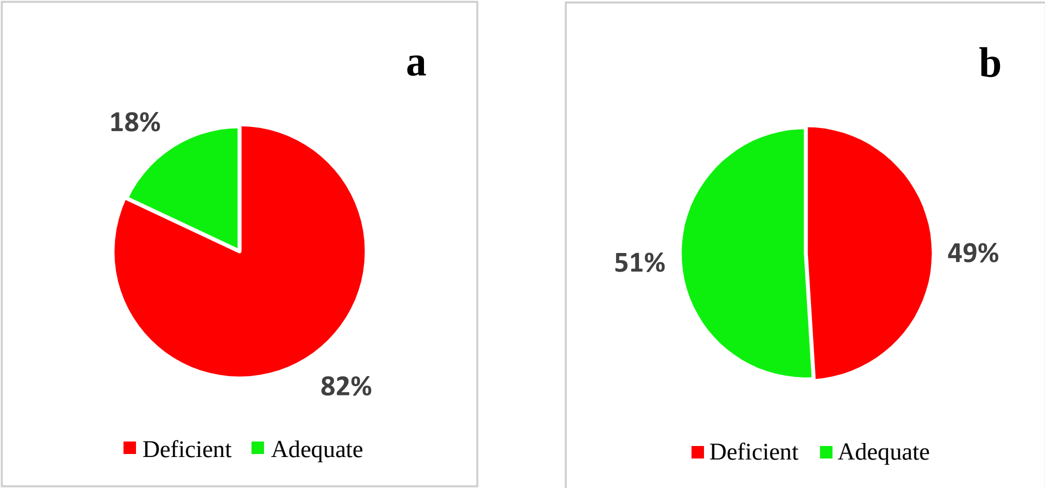

Fig. 36. Frequency of available sulphur classes of (a) pre-flood soils in comparison with (b) post-flood soils of AEU 14 in Idukki district of Kerala

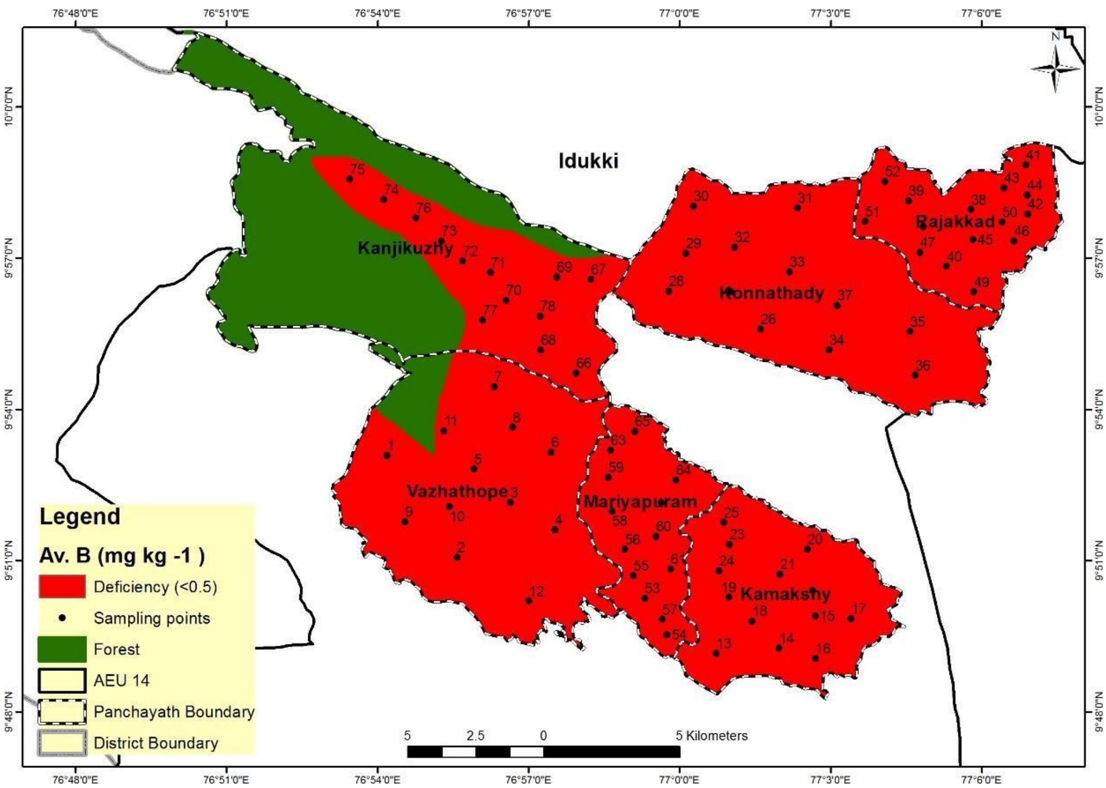

Fig. 37. Spatial distribution of available B of post-flood soils of AEU 14 in Idukki district of Kerala

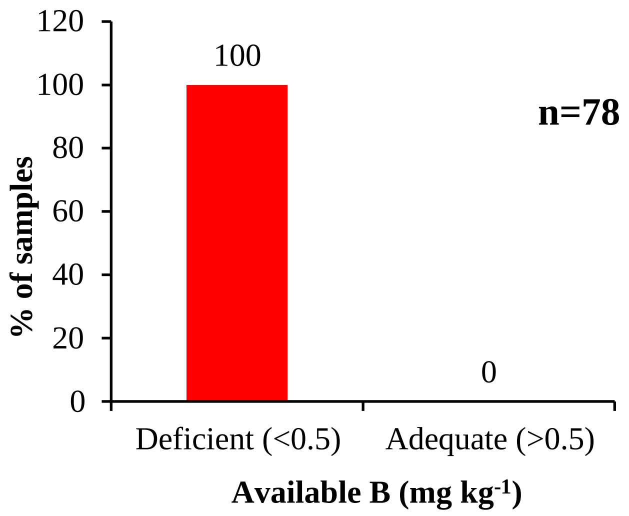

Fig. 38. Frequency distribution of available B of post-flood soils of AEU 14 in Idukki district of Kerala

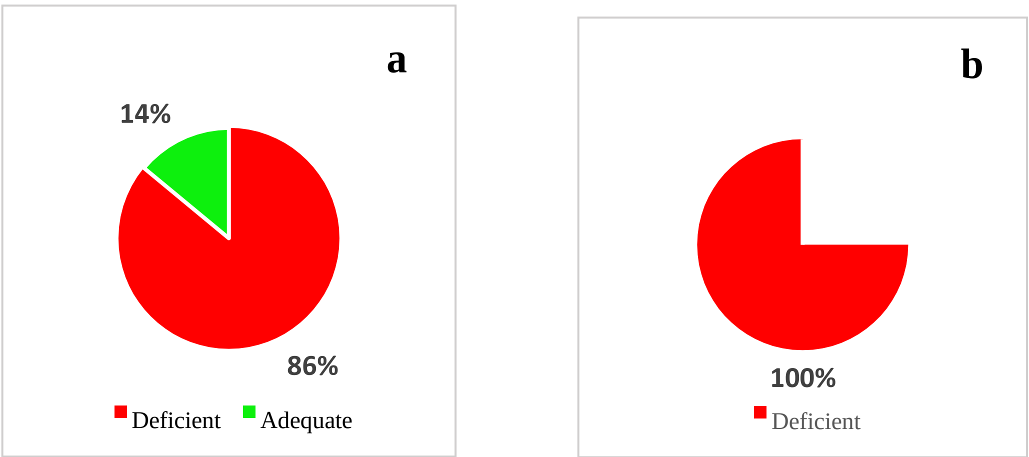

Fig. 39. Comparison of frequency of available boron status in (a) pre-flood and (b) post-flood soils of AEU 14 in Idukki district of Kerala

5.1.3. Biological Attributes

5.1.3.1. Acid Phosphatase Activity

Acid phosphatase activity ranged between 2.2 to 75.2 µg nitrophenol g^{-1} h^{-1} with a mean value of 24.6 µg nitrophenol g^{-1} h^{-1}. Forty-six and thirty seven percent of the soil samples had an acid phosphatase activity between 10-25 and 25-50 µg nitrophenol g^{-1} h^{-1} respectively (Fig. 40). Acid phosphatase activity might be higher due to high organic matter content of the soils of AEU 14. It could be due to the fact that, organic matter is the seat of microbial population and activity. Similar results were obtained by Kumari *et al*. (2017). Organisms can assimilate only dissolved phosphate and therefore, phosphatase activity plays a fundamental role in the transformation of P from soil organic sources into available forms. The phosphatase activity relies largely on the fact that phosphomonoestarases are enzymes most susceptible to changes in soil reaction. The optimum pH of soil for the activity of acid phosphatase is 4.0-6.5 (Lemanowicz, 2018). The fact that the entire set of seventy eight samples subjected to study in the flood affected regions in the present study were within a range of 4.66 to 6.49 has been ideal for the favourable acid phosphatase activity in these soils. Huang *et al.* (2011) observed that precipitation influenced acid phosphatase activity in soils. They observed that the value of soil acid phosphatase activity in the wet season was 1.33 times greater than in the dry season. However, they also found that water brought by natural rainfall was sufficient for plant growth because of large rainfall occurring in the wet season. More water had no competitive advantage. As soil moisture was already high, more water input as a result of flooding due to heavy rainfall would impede the diffusion of oxygen in the soils. In an anoxic condition, plant root growth and microbial activity would be restrained, which could be responsible for the significantly lower acid phosphatase activity. Therefore, flooding of soils would have a detrimental effect on acid phosphatase activity. Nitrogen content is likely to stimulate the activity of phosphatases since nitrogen is essential for some enzyme synthesis (Margalef *et al*., 2017). And there exist a positive correlation between acid phosphatase activity and EC, soil organic carbon, available N, P, K, Ca and Mg. These results are in confirmation with the results obtained by Vandana (2012), which showed significant positive correlation of phosphatase with organic carbon and insignificant correlation with pH. Gianfreda *et al.* (2005)

found a significant positive correlation of phosphatase with organic carbon content, available N and available P.

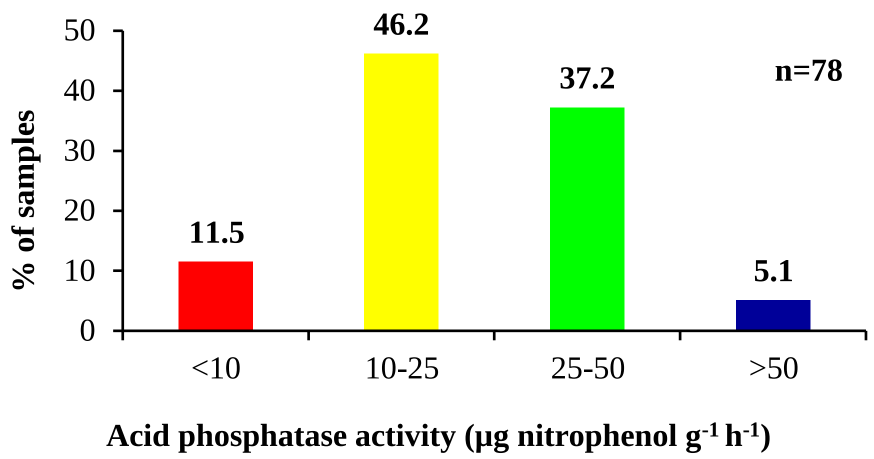

Fig. 40. Frequency distribution of acid phosphatase activity of post-flood soils of AEU 14 in Idukki district of Kerala

5.1.4. Variations in soil properties in areas with deposition and erosion

Soil properties showed variation in areas with erosion and deposition. Erosion was prominent in Vazhathope panchayath whereas deposition was prominent in Rajakkad, Kamakshy and Konnathady panchayaths. Erosion might have resulted in the lowest EC value of 0.189 ds m^{-1} (Table 11) which might be due to heavy leaching of soluble salts by the floodwaters. Vazhathope panchayath had the lowest mean value for organic carbon, available nitrogen, available phosphorus, available potassium, available calcium and available magnesium. The lowest value of available nutrients can be attributed to the heavy erosion which happened during flood in Vazhathope panchayath. A very high mean value of available calcium (1019 mg kg^{-1}) in Rajakkad panchayath might be due to flow of basic cations by the flood water downhill through the slopy terrain and deposition in the valley areas of agricultural lands under vegetables and paddy.

5.2. SOIL QUALITY INDEX

Soil health plays a major role in the life support system on earth and thus viewed as the component of soil quality and ecosystem health which represents the properties of soil as a living system. Soil quality is known as the degree of fitness of soil for a particular use or capacity of soil to function (Karlen *et al*., 1997). Soil health and soil quality have been synonymously used in recent years. Soil quality index of the post-flood soils of AEU 14 was worked out from the 10 parameters of MDS; available Ca, organic carbon, acid phosphatase activity, EC, available Mg, clay percent, silt percent, available B, pH, and water stable aggregates. The spatial distribution of RSQI is given in Fig. 41. Relative soil quality index of the soil samples ranged from 35 to 81.3 per cent with a mean value of 66.6 per cent . Among the total soil samples, 59 and 37 per cent t of the samples were medium and high in quality respectively (Fig. 42). The contribution of organic carbon to soil quality index was substantial as organic carbon emerged as an important indicator contributing to the soil quality index. The soil organic carbon has been globally used as a soil quality indicator owing to its crucial role in multiple soil processes including nutrient cycling and storage, soil aggregation, and as the main food source for heterotrophic microorganisms (Raiesi, 2017). The medium to high soil quality of the soils of AEU 14 may be attributed to the inherent soil properties of hill zone soil, increased deposition, reduced mineralisation, type of vegetation and microclimate (Nair *et al*., 2013). The mean value of relative soil quality index was the highest for Rajakkad and lowest for Vazhathope panchayath. Poor soil quality index of Vazhathope panchayath is because of mostly lower values of soil attributes considered for computing soil quality. Vazhathope panchayath had the lowest available Ca, organic carbon, acid phosphatase activity, and available magnesium whereas Rajakkad panchayath had a higher mean value for all these attributes. Hence relative soil quality index was the highest in Rajakkad and lowest in Vazhathope.

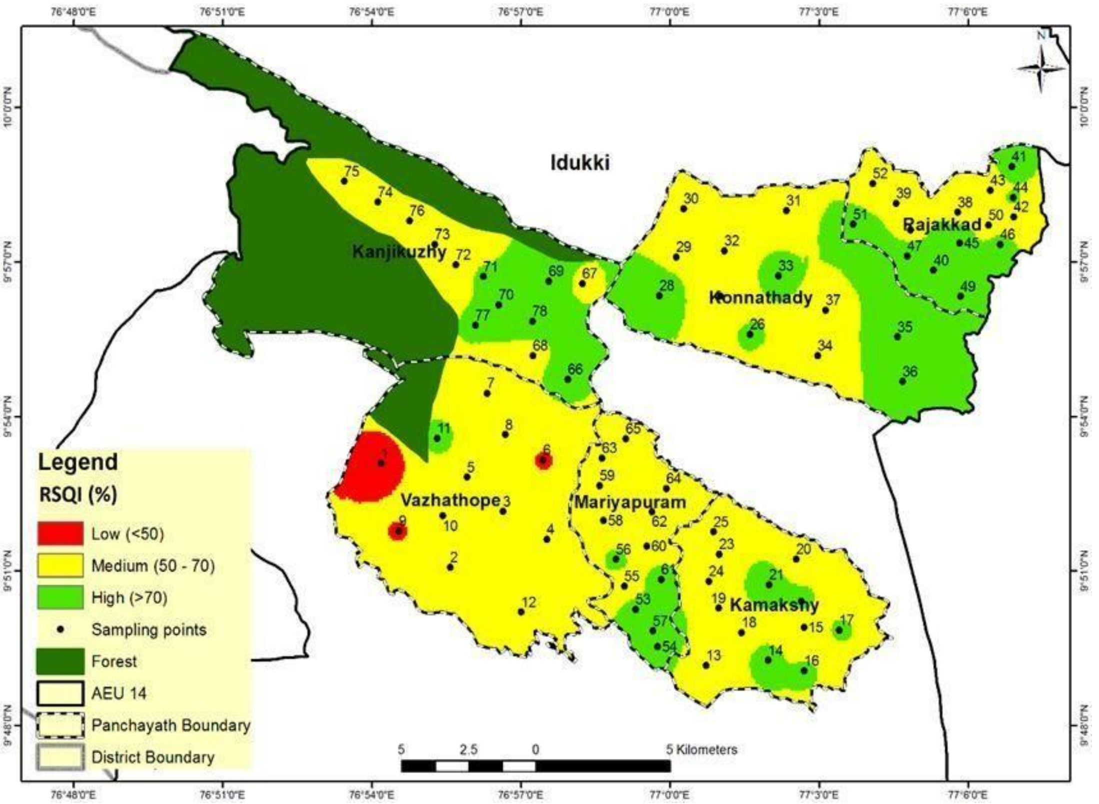

Fig. 41. Spatial distribution of RSQI of post-flood soils of AEU 14 in Idukki district of Kerala

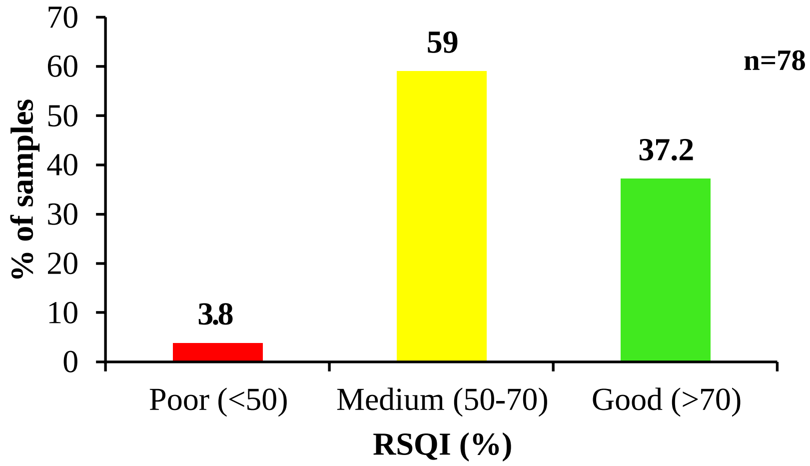

Fig. 42. Frequency distribution of RSQI of post-flood soils of AEU 14 in Idukki district of Kerala

5.3. NUTRIENT INDEX AND LAND QUALITY INDEX

Nutrient indices were computed for the soil organic carbon content and the major primary nutrients nitrogen, phosphorus, potassium and categorised as low, medium and high as per ratings for these indices. Soil nutrient index of the study area in terms of organic carbon was high for all the five panchayaths and medium for Vazhathope (Fig. 43). Chandrakala *et al*., (2018) also reported high organic carbon status in Idukki. Fertility status of the soils in terms of nutrient index of nitrogen was rated as medium throughout all the flood affected panchayaths of the Southern High Hills of Idukki district (Fig. 44). This gives a clear indication of the losses of nitrogen that has occurred in the flood waters by way of leaching and the indispensability for making good the losses by replenishment of the nitrogen status through addition of fertilizer input for sustaining soil health and productivity. Fertility status of the soil in terms of nutrient index of phosphorus content was rated as high in all flood affected panchayaths with the lone exception of Rajakkad panchayath which recorded only a medium status (Fig. 45). According to Natarajan *et al.*, (2013) majority of the soils of Idukki under all the major crops like cardamom, pepper, coffee, coconut had high available P status. A low nutrient index value of potassium was recorded only for Vazhathope panchayath out of the six flood affected panchayaths (Fig. 46). This is reflective of Vazhathope panchayath constituting the major share in the 14.1 per cent of the soil available potassium status rated as low (Fig. 25).

Soil organic carbon stock was used to estimate the land quality index. For the estimation of soil organic carbon stock in the soils, the bulk density and organic carbon data pertaining to the respective soil samples were used. The soil organic carbon stock ranged from 0.77 to 7.91 kg m^{-2} with a mean value of 3.35 kg m^{-2}. Thematic map of land quality index is given in Fig. 47. The organic carbon content of the soils were high which might be due to slow organic matter decomposition at higher altitudes, where temperature is low and rainfall is high (Shalimadevi and Anil Kumar, 2009). Moreover, the bulk density was generally low around 1 Mg cm^{-3}. In all the samples, the soil organic carbon stock was estimated to a depth of 15cm. Among the total samples, 60 and 35 per cent of samples belonged to very low and low category of land quality index rating respectively (Fig. 48). Overall, the low amount of soil organic carbon stock in0-

15 cm depth can be ascribed to low bulk density and low volume of soil. The land quality index of Vazhathope, Konnathady, and Mariyapuram panchayaths were rated as very low. This is indicative of the depleting and degradative nature of the soil organic carbon stock in the soils of these panchayaths.

5.4. SUGGESTED INTERVENTIONS IN AEU 14 OF IDUKKI DISTRICT

During the period of flood and debris flow, sedimentation occurred on many terrains masking the cultivated lands, particularly in Vazhathope and Kanjikuzhy panchayaths. The sediment materials constituted largely by sand fractions are likely to create perennial issues and this needs to be removed wherever possible to make future cultivation of crop successful. This can be accomplished through purposeful tillage in open areas to facilitate better infiltration of water. Future erosions in some vulnerable area which remove fertile soils could be prevented by providing a grass cover, thus giving enough room for the flood water to flow.

- Management of soil acidity is important. Liming of acid soils in accordance with soil test results is highly essential.
- Regular application of organic matter or recycling organic matter is essential to maintain favourable chemical environment although the organic carbon content of the soils are high. Soil organic carbon was high with a mean of 1.97 per cent (Table 11) which requires the application of organic manures as per POP recommendation and N @ 63 per cent of the POP recommendation.
- The use of phosphatic fertilisers can be reduced to a large extent in all panchayaths with the exception of Rajakkad based on soil test results.
- Available K was medium in some area and high in most of the area with a mean value 307 kg ha^{-1} (Table 12). Potassium sources can be applied @ 48 per cent of the recommendation. Apply potassium fertilisers in as many splits as possible to reduce losses, particularly in Vazhathope panchayath.
- Available Ca was adequate for most of the area with a mean value of 796 mg kg^{-1} (Table 13). Application of lime as per the lime requirement is sufficient.

- Application of magnesium sulphate in Mg deficient areas specifically in Vazhathope and Mariyapuram panchayaths @ 80 kg ha^{-1} and in S deficient areas @ 25 kg ha^{-1} will be beneficial.
- Since boron deficiency is acute in the entire AEU, regular application of borax for crop plants is advisable. For cardamom, farmers may go for foliar application of borax. Application of @ 10 kg ha^{-1} or 0.5 per cent solution of borax as foliar spray can be done.
- Location specific fertiliser recommendations needs to be worked out based on soil nutrient status of individual farmers of each panchayath.

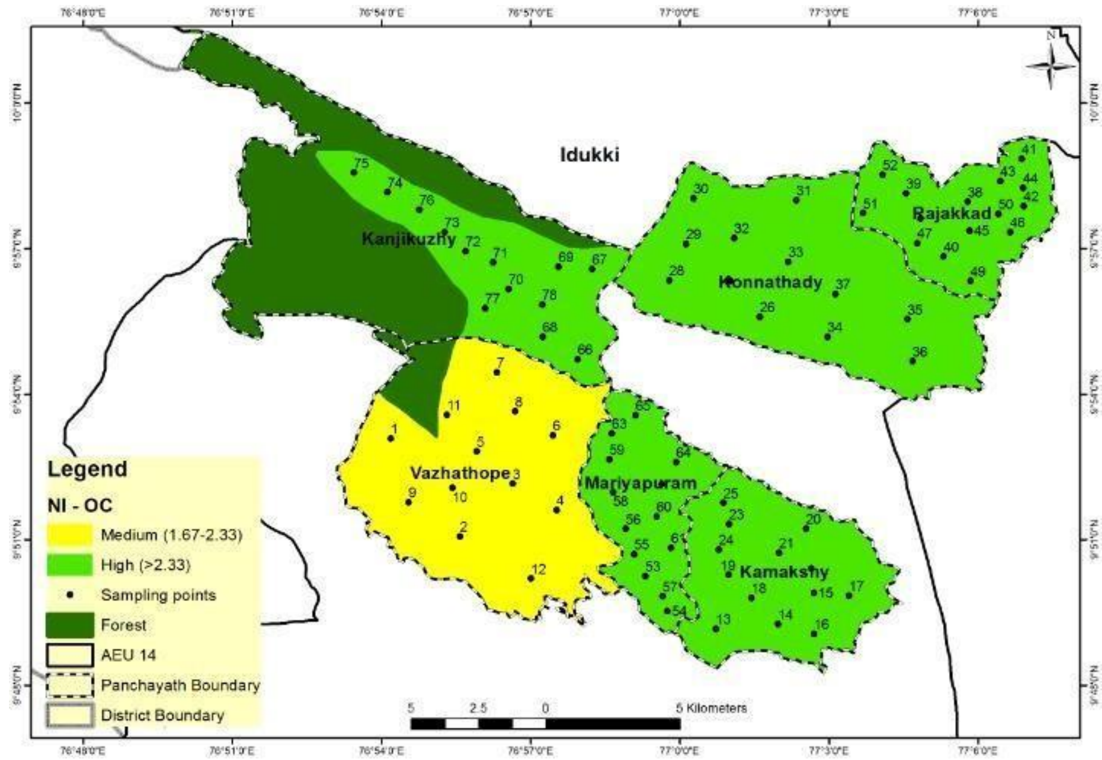

Fig. 43. Spatial variability of nutrient index of organic carbon in post-flood soils of AEU 14 in Idukki district of Kerala

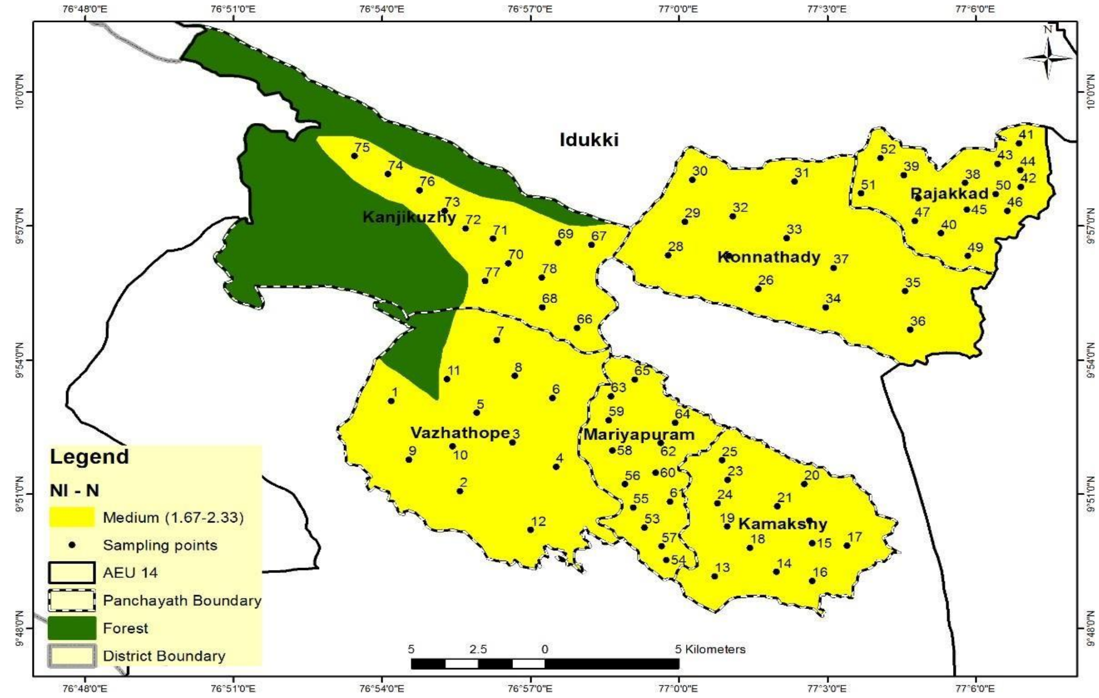

Fig. 44. Spatial distribution of nutrient index of available N in post-flood soils of AEU 14 in Idukki district of Kerala

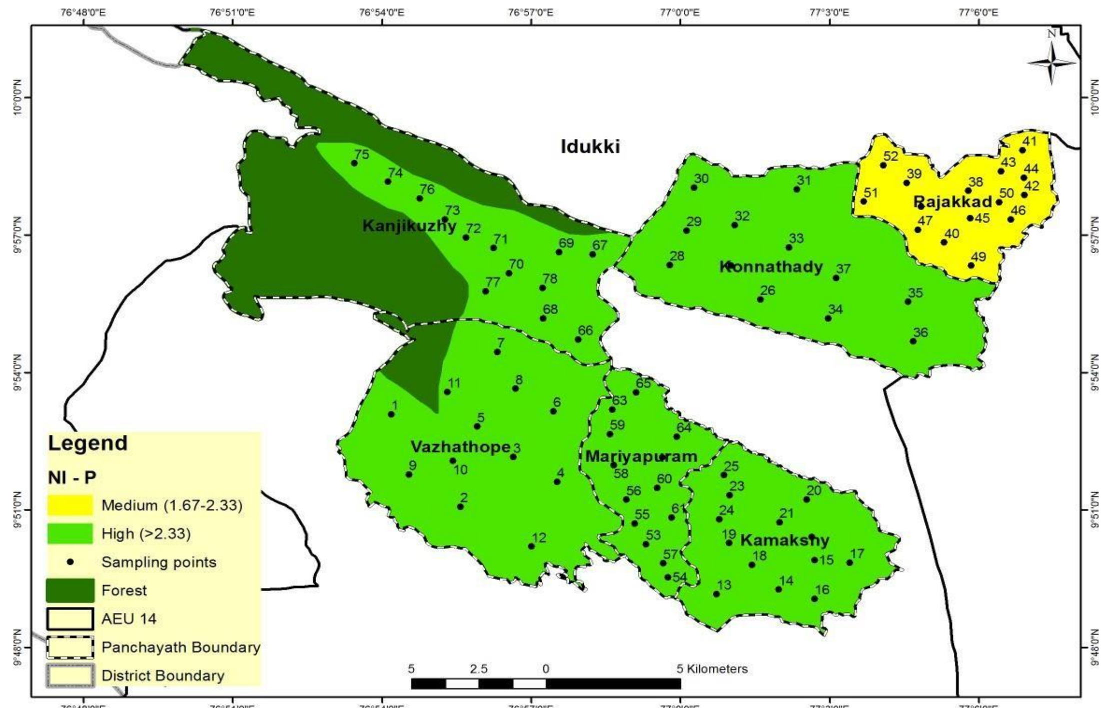

Fig. 45. Spatial distribution of nutrient index of available P in post-flood soils of AEU 14 in Idukki district of Kerala

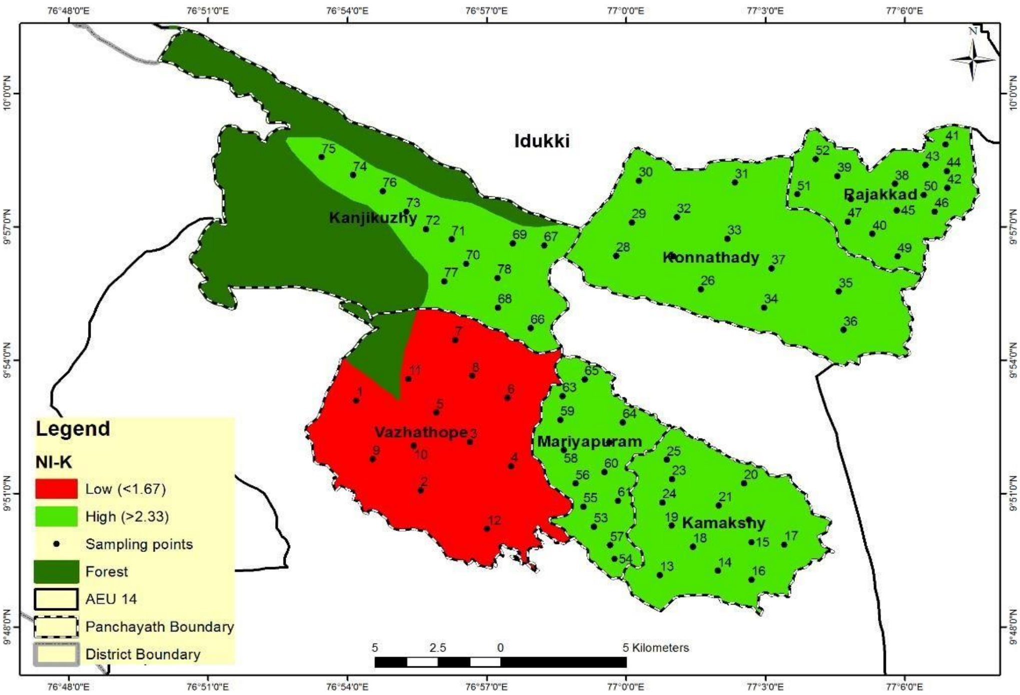

Fig. 46. Spatial distribution of nutrient index of available K in post-flood soils of AEU 14 in Idukki district of Kerala

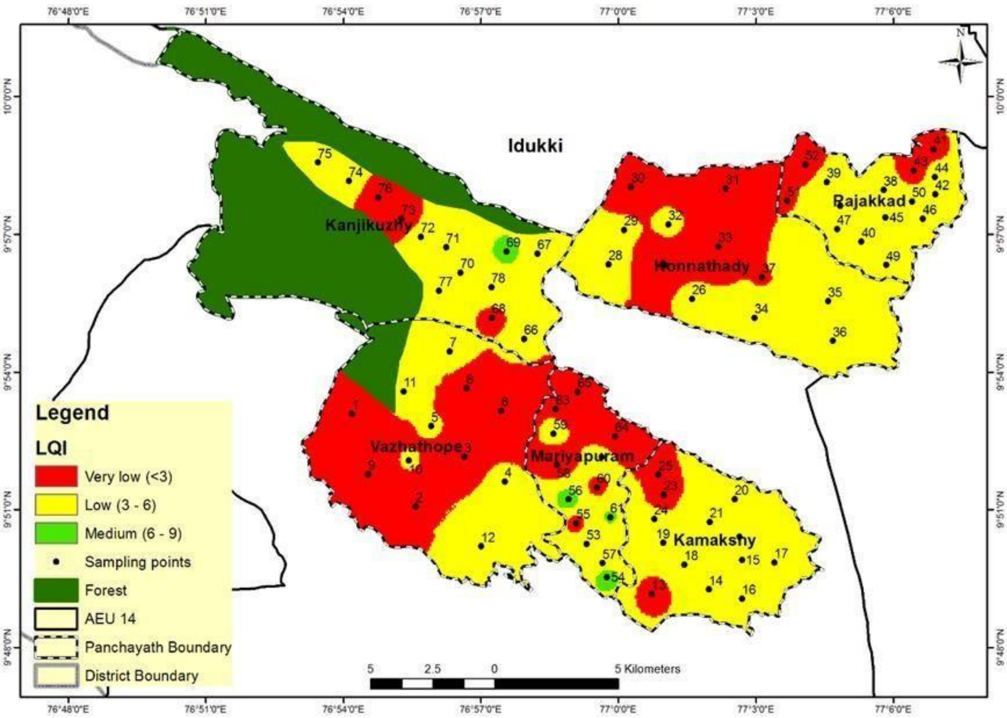

Fig. 47. Spatial distribution of land quality index of post-flood soils of AEU 14 in Idukki district of Kerala

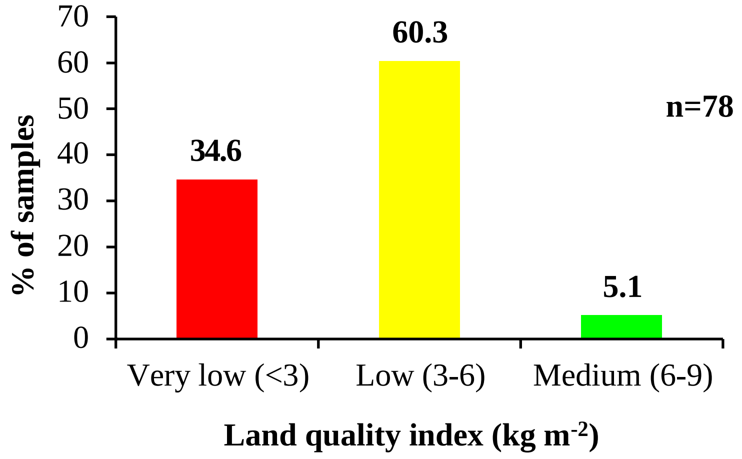

Fig. 48. Frequency distribution of acid land quality index of post-flood soils of AEU 14 in Idukki district of Kerala

Summary

6. SUMMARY

The present study entitled 'Assessment of soil quality in the post-flood scenario of AEU 14 in Idukki district of Kerala and generation of GIS maps' was done with the objective to evaluate the soil quality of post-flood soils of AEU 14 of Idukki district, to work out soil quality index and to develop georeferenced database and maps on soil characterization.

A survey was conducted and seventy-eight georeferenced soil samples were collected from the severely flood affected panchayaths, viz. Vazhathope, Kamakshy, Konnathady, Rajakkad, Mariyapuram and Kanjikuzhy. Pepper, cardamom, coffee, cocoa, coconut, nutmeg, tea and vegetables were the major crops in the area. Majority (91 %) of the farmers belonged to the small and marginal (<2 ha) category. The farmers followed organic practices and liming integrated with conventional fertilisers. Soil samples collected from a depth of 0-20 cm were analysed for their physical (bulk density, particle density, porosity, texture, water holding capacity, depth of sand/ silt/ clay deposition, soil moisture and aggregate analysis), chemical (pH, EC, OC, available N, P, K, Ca, Mg, S, B) and biological (acid phosphatase) attributes.

The minimum data set of indicators for computing the soil quality index was selected by principal component analysis. Six principal components were extracted from which ten indicators that highly influenced the soil quality were identified, viz. available calcium, organic carbon, available magnesium, acid phosphatase activity, clay percent, silt percent, pH, electrical conductivity, water stable aggregates and available boron. Scores and weights were assigned to each indicator, and they were aggregated to compute the soil quality index. The relative soil quality index of the soils were computed and soils were categorised as 'poor', 'medium' and 'good' using the relative soil quality index (RSQI) value. Thematic maps were generated in ArcGIS software for soil texture, pH, organic carbon, available N, P, K, Ca, Mg, S, B, relative soil quality index, land quality index, and nutrient index for organic carbon, available N, P, K. Correlations were worked out between physical, chemical and biological parameters. The main findings are summarized below.

- Bulk density of soil ranged from 0.90 to 1.48 Mg m^{-3} with a mean value of 1.16 Mg m^{-3}. Bulk density of 73 per cent samples were less than 1.2 Mg m^{-3}.
- Particle density of soil samples ranged from 1.90 to 2.79 Mg m^{-3} with a mean value of 2.14 Mg m^{-3}. Particle densities of 68 per cent samples were less than 2.2 Mg m^{-3}.
- The porosity of soil ranged from 28.8 to 55.8 per cent with a mean value of 45.8 per cent. 72 per cent and 26 per cent soils have porosity between 30-50 and 50-70 respectively.
- Dominant soil textural classes in the flood affected panchayaths of AEU 14 were clay and clay loam.
- A sand bar of 5 cm depth was observed in Vazhathope and Kanjikuzhy panchayaths due to consistent deposition of sedimentary sand fractions of soil in the areas of banks of river of the panchayaths
- The moisture content of soil samples varied from 2.0 to 39.3 per cent with a mean value of 11.32 per cent. The moisture content of 55 percent samples were less than 10 per cent.
- Water holding capacity of soils varied from 29.6 to 62.7 per cent with a mean value of 43.6 per cent. Eighty percent of the soil samples had a WHC between 30 to 50 per cent.
- Mean weight diameter recorded from the various locations ranged from 0.59 to 2.10 mm with a mean value of 1.23 mm. MWD of 40 per cent samples were less than 1 mm.
- Per cent of water stable aggregates varied between 52.4 to 86.8 per cent
- The pH ranged from 5.57 to 5.78. About 37, 28, and 26 per cent soils belonged to moderately acid (5.5-6.0), strongly acid (5.0-5.5) and slightly acid (6.0-6.5) classes.
- The mean EC values of the six panchayaths varied from 0.054 to 0.189 dS m^{-1}.
- Soil organic carbon content varied from 1.51 to 2.28 per cent . Seventy per cent of the soils were rated high in organic carbon.

- Available nitrogen content varied from 329 to 428 kg ha^{-1}. Majority (67 %) of the soils were medium in available nitrogen content
- The mean value of available phosphorus content of soils in the six panchayaths varied from 41.2 to 67.5 kg ha^{-1}.
- The available potassium content in the soils varied from 144 to 396 kg ha^{-1}. About 53.8 per cent samples were high in available potassium
- Available calcium content of soils varied from 448 to 1019 mg kg^{-1} and 89.7 per cent samples were adequate in available calcium
- The mean value of available magnesium content of soils in the six panchayaths varied from 83 to 171 mg kg^{-1}. Among the total soils sampled, 51.3 per cent samples were adequate in available magnesium
- The mean value of available sulphur varied from 7.8 to 14.3 and about 49 per cent samples were deficient in available sulphur
- The mean value of available boron in the six panchayaths varied from 0.14 to 0.27 mg kg^{-1}. All the samples were deficient in available boron
- Acid phosphatase activity ranged between 2.2 to 75.2 µg nitrophenol g^{-1} h^{-1} with a mean value of 24.6 µg nitrophenol g^{-1} h^{-1}.
- Relative soil quality index of the soil samples ranged from 35 to 81.3 per cent with a mean value of 66.6 per cent. Fifty nine and 37 per cent of the samples were medium and high in quality respectively
- Nutrient index of the study area in terms of organic carbon was high for five panchayaths and medium for Vazhathope while the nutrient index of nitrogen was medium for all the panchayaths. Nutrient index of phosphorus was high in 5 panchayaths and medium in Rajakkad panchayath. Nutrient index of potassium was low for Vazhathope and high for the other five panchayaths
- The soil organic carbon stock ranged from 0.77 to 7.91 kg m^{-2} with a mean value of 3.35 kg m^{-2}. Among the total samples, 60 and 35 per cent of samples belonged to very low and low category of land quality index rating respectively
- In comparison with other flood affected panchayaths, soils of Vazhathope panchayath was comparatively vulnerable to floods in terms of soil physical, chemical and biological attributes. Apart from bearing sand deposits (5 cm),

these soils recorded the lowest organic carbon content, available nitrogen, phosphorus, potassium, calcium, magnesium status and acid phosphatase activity. Among quality indices, Vazhathope had the lowest relative soil quality index, and was low in land quality index and potassium nutrient index.

- In terms of soil quality, soils of Rajakkad panchayath exhibited better tolerance to floods and was resilient as compared to the other five flood affected panchayaths. The highest status for available phosphorus, calcium and acid phosphatase activity were observed in Rajakkad panchayath. Among quality indices, soils of Rajakkad superseded the soils of the other five flood affected panchayaths with the highest relative soil quality index, comparatively higher land quality index and a high nutrient index for organic carbon and potassium.
- Moderation in soil reaction, an enhancement in the organic carbon content, available P, K, Ca, and reduction in deficiency status of Mg and S has occurred in the post- flood soils, boron being an exception.
- There has been no serious decline in the soil fertility in the post-flood soils of AEU 14.
- The sediment materials on the soils are likely to create perennial issues and these needs to be removed wherever possible to make future cultivation of crop successful.
- Liming of acid soils, regular application of recommended doses of nitrogenous fertilisers, application of potassium fertilisers in splits, application of magnesium sulphate in Mg and S deficient area, regular application of borax for plant crops are the suggested interventions for the soils of AEU 14 of Idukki district of Kerala.

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ASSESSMENT OF SOIL QUALITY IN THE POST-FLOOD SCENARIO OF AEU 14 IN IDUKKI DISTRICT OF KERALA AND GENERATION OF GIS MAPS

by

SREEJITHA M BABU

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ABSTRACT

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VELLAYANI, THIRUVANANTHAPURAM – 695 522

KERALA, INDIA

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ABSTRACT

A study entitled 'Assessment of soil quality in the post-flood scenario of AEU 14 in Idukki district in Kerala and generation of GIS maps' was carried out with objectives to evaluate the soil quality of the flood affected areas of AEU 14 in Idukki district, to work out the soil quality index and to map the various soil attributes and quality using GIS techniques.

On the basis of the survey conducted, seventy eight georeferenced soil samples were collected from the severely flood affected panchayaths *viz*. Vazhathope, Kamakshy, Konnathady, Rajakkad, Mariyapuram, and Kanjikuzhy. Pepper, cardamom, coffee, cocoa, coconut, nutmeg and vegetables were the major crops in the area. Majority (91 %) of the farmers were small and marginal, adopting organic practices and liming integrated with conventional fertilisers.

The soil samples, collected from a depth of 0-20 cm, were characterized for physical (bulk density, particle density, porosity, texture, water holding capacity, depth of sand/ silt/ clay deposition, soil moisture and aggregate analysis), chemical (pH, EC, OC, available N, P, K, Ca, Mg, S, B) and biological (acid phosphatase) attributes. The minimum data set of indicators for computing the soil quality index was selected by principal component analysis. Six principal components were extracted from which ten indicators that highly influenced the soil quality were identified, viz. available calcium, organic carbon, available magnesium, acid phosphatase activity, clay per cent, silt per cent, pH, electrical conductivity, water stable aggregates and available boron. Scores and weights were assigned to each indicator, and they were aggregated to compute the soil quality index. The relative soil quality indices of the soils were computed. Thematic maps of the analysed soil parameters were generated in ArcGIS software and interpolated by Inverse distance weighting method. Correlations were worked out between physical, chemical and biological parameters. Bulk density of 67 per cent sam- ples were in a range of 1.0 to 1.2 Mg m^{-3} and particle density of 72 per cent samples were in the range 2.0 to 2.4Mg m^{-3}. Mean value of water holding capacity ranged be- tween 40-50 per cent. Soil porosity of 58 per cent samples was between 40 and 50 percent.

Soil textural classes of the samples were clay (42 %), clay loam (27 %), sandy clay loam (17 %), sandy clay (9 %) and loamy (5 %).

Based on soil pH, the samples belonged to moderately acid (37 %), strongly acid (28 %), slightly acid (25 %) and very strongly acid (9 %) classes. Electrical conductivity was < 2 dSm^{-1}. Organic carbon content was high in 70 per cent of the soils. Available nitrogen was medium in 67 per cent of the samples and available phosphorus was high in 65 per cent of the soil samples. Available K status was high in 54 per cent and medium in 32 per cent of the soils. Available Ca was adequate in 89 per cent whereas Mg and S were deficient in 49 per cent of the samples and B was deficient in 100 per cent of the samples. Significant correlation was observed between clay content and water holding capacity of the soil, and acid phosphatase activity and organic carbon content of the soil.

Nutrient index of organic carbon was high in all panchayaths except Vazhathope which was medium. Nutrient index of available K was low in Vazhathope and high in other panchayaths. Land quality index of the soil samples were very low (35 %), low (60 %) and medium (5 %). Based on the relative soil quality index value, soils were categorized as medium (59 %), good (37 %) and poor (4 %). Relative soil quality index was the highest in Rajakkad and lowest in Vazhathope panchayath. Vazhathope panchayath was comparatively vulnerable to floods in terms of soil physical, chemical and biological attributes. Rajakkad panchayath exhibited better tolerance to floods and was resilient.

Compared to 2013 data, a moderation in soil reaction, an increase in the organic carbon content, available P, K, Ca, and alleviation in deficiency status of Mg and S was observed in the post- flood soils, boron being an exception. An enhancement of soil quality parameters has been facilitated in the post-flood soils of AEU 14.

Liming of acid soils, regular application of recommended doses of nitrogenous fertilisers, application of potassium fertilisers in splits, application of magnesium sulphate in Mg and S deficient area, application of borax for crop plants are the suggested interventions for the soils of AEU 14 in Idukki district of Kerala.

Appendices

APPENDIX I

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

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

APPENDIX II

Area and crop management of sampled locations

Sl. no.	Holding size	Crops	Nutrient management
1.	0.3 acre	Cocoa	Organic
2.	6 acre	Nutmeg, cocoa, pepper	INM
3.	2 acre	Pepper, coconut, arecanut, cardamom, nutmeg	INM
4.	0.5 acre	Cocoa	Conventional
5.	0.7 acre	Coconut, cocoa, coffee	Organic
6.	0.2 acre	Nutmeg, cocoa, coconut	Organic
7.	3 acre	Pepper, nutmeg, coconut, cocoa	INM
8.	3.5 acre	Pepper, rubber	INM
9.	0.75 acre	Nutmeg, banana, coconut, vegetables, cassava	Conventional
10.	0.2 acre	Pepper, nutmeg, cardamom, banana	Organic
11.	1 acre	Cocoa, coffee	INM
12.	0.55 acre	Nutmeg, cocoa, coconut, banana	INM
13.	1.75 acre	Cardamom	INM
14.	1.40 acre	Banana. Tea	INM
15.	3 acre	Tea, cardamom	INM
16.	2.75 acre	Cardamom, coffee, pepper	INM
17.	1.25 acre	Cocoa, cassava, coconut, coffee, banana	Organic
18.	0.25 acre	Pepper, coconut	Organic
19.	2.15 acre	Cardamom, pepper, vegetables	Conventional
20.	0.25 acre	Cardamom, pepper	Organic
21.	8 acre	Pepper, cardamom, coconut, coffee, nutmeg	INM
22.	1 acre	Pepper, cardamom, banana, cassava	INM
23.	2 acre	Pepper, banana	INM
24.	0.35 acre	Vegetables	Organic
25.	2.5 acre	Pepper, coffee, nutmeg, cardamom, banana	INM
26.	1.5 acre	Banana, pepper, coffee, cardamom	INM
27.	0.37 acre	Nutmeg, cocoa, coconut, banana	Conventional
28.	3 acre	Banana, cocoa, nutmeg, cassava, coffee	INM
29.	1.5 acre	Cardamom, pepper, coconut	Organic
30.	2 acre	Nutmeg, cocoa	INM
31.	1.20 acre	Banana, pepper, cardamom	INM
32.	0.8 acre	Cocoa, nutmeg	Conventional
33.	4 acre	Cardamom, cocoa, rubber, pepper	INM
34.	7 acre	Cocoa. Nutmeg, pepper, coconut	INM
35.	0.25 acre	Pepper, nutmeg	Organic
36.	2 acre	Cardamom, pepper, nutmeg	INM
37.	4.5 acre	Cardamom, cocoa, nutmeg	INM
38.	1.5 acre	Banana, vegetables	INM
39.	1 acre	Cardamom, pepper, coffee, nutmeg	Organic
40.	1.2 acre	Banana	INM
41.	2 acre	Pepper, cardamom, cocoa	INM
42.	0.15 acre	Coffee, pepper	Organic

43.	4 acre	Banana, coffee, pepper, cardamom	INM
44.	2 acre	Cardamom, pepper	INM
45.	2 acre	Cardamom	INM
46.	1 acre	Cardamom	Conventional
47.	6 acre	Cardamom, pepper, nutmeg, coffee, paddy	INM
48.	3 acre	Pepper, cardamom, banana, vegetables	INM
49.	2 acre	Cardamom, pepper	INM
50.	2 acre	Cardamom, pepper, cocoa	INM
51.	1.2 acre	Cardamom, pepper, nutmeg	INM
52.	2 acre	Cardamom, pepper, paddy	INM
53.	0.1 acre	Banana, pepper	Organic
54.	4 acre	Cardamom, tea	INM
55.	5 acre	Pepper, Banana	INM
56.	2.5 acre	Cardamom, pepper, nutmeg	INM
57.	2.35 acre	Cardamom, pepper, nutmeg, cocoa	INM
58.	1.5 acre	Coffee, pepper, nutmeg	INM
59.	3 acre	Pepper, nutmeg, coffee	INM
60.	3.2 acre	Coffee, coconut, nutmeg, pepper, cocoa	Organic
61.	10 acre	Cocoa, cardamom	INM
62.	2.15 acre	Cardamom, tea, pepper	Organic
63.	3.5 acre	Pepper, cocoa, nutmeg, coconut	INM
64.	0.5 acre	Nutmeg, cocoa, pepper	Conventional
65.	3 acre	Nutmeg, coconut, banana, pepper	INM
66.	0.25 acre	Coffee, pepper	Organic
67.	0.5 acre	Cocoa, coconut	Organic
68.	0.6 acre	Pepper, cocoa	Organic
69.	5 acre	Nutmeg, pepper, cocoa	INM
70.	1 acre	Cocoa	INM
71.	1.2 acre	Nutmeg, cocoa, pepper, banana	INM
72.	2 acre	Pepper, cocoa, nutmeg	INM
73.	1 acre	Pepper, cardamom	INM
74.	1 acre	Pepper, cocoa, coconut	INM
75.	0.5 acre	Nutmeg, cocoa	Organic
76.	1.15 acre	Pepper, cocoa, banana, nutmeg, coconut	Organic
77.	1.5 acre	Cocoa, pepper, nutmeg, cardamom	INM
78.	1.5 acre	Nutmeg, cocoa, pepper, banana	INM

APPENDIX III

Physical and biological properties of soil samples

Sample no.	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity (%)	Moisture (%)	WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Acid phos. Activity (µg nitro-phenol g^{-1} h^{-1})
1	1.10	2.35	53.0	10.2	47.0	1.83	69	48	10	42	2.3
2	1.36	2.38	42.7	26.7	46.2	1.57	82.8	48	15	37	8.0
3	1.06	2.32	54.4	10.0	42.5	0.86	64.8	38	20	42	8.5
4	1.48	2.54	41.8	31.3	32.5	0.66	64.8	33	20	47	2.2
5	1.07	2.04	47.6	5.4	50.1	1.56	66.4	48	10	42	16.9
6	1.11	2.39	53.4	2.0	45.0	1.43	63.6	43	20	37	7.5
7	1.00	2.11	52.6	5.0	35.3	0.77	66.4	33	20	47	14.9
8	1.09	2.00	45.3	2.5	42.8	0.79	65.2	38	10	52	10.3
9	1.06	2.37	55.4	7.6	53.9	1.32	65.8	53	25	22	3.5
10	1.10	2.04	46.3	8.2	43.3	0.93	70.2	43	25	32	15.8
11	1.12	2.04	45.1	2.2	34.1	1.02	72.6	33	30	37	25.1
12	1.42	2.08	32.0	21.7	40.9	0.97	62	38	20	42	20.4
13	1.15	2.24	48.7	24.0	35.0	0.89	61.8	33	15	52	15.0
14	1.06	2.15	50.6	6.2	34.8	1.77	75.6	33	30	37	17.5
15	0.99	2.06	51.9	11.9	30.4	0.94	71.2	23	15	62	14.9
16	1.03	1.90	45.8	6.4	52.5	1.76	75.4	48	10	42	17.4
17	1.27	2.29	44.4	3.2	42.1	0.88	73.4	38	30	32	21.2
18	1.33	2.07	35.6	6.9	35.2	0.83	61	28	30	42	11.4
19	1.15	2.30	50.0	35.7	36.4	1.00	69	33	30	37	17.5
20	1.01	1.94	47.8	20.8	62.7	2.10	69.8	63	10	27	23.4
21	1.28	2.06	38.1	3.5	48.4	1.35	75.4	48	15	37	33.0
22	1.25	2.03	38.2	9.5	42.4	1.03	73	40.5	12.5	47	24.5
23	1.30	2.21	41.0	8.2	34.5	1.29	71.2	33	25	42	28.3
24	1.22	2.06	40.9	23.4	39.7	0.98	63	38	25	37	19.5
25	1.26	2.12	40.5	13.3	49.5	1.00	63.6	45.5	22.5	32	14.5
26	1.44	2.10	31.4	3.6	41.3	1.30	79.2	43	20	37	22.3
27	1.14	2.31	50.5	39.3	29.6	0.59	52.4	23	20	57	18.8
28	1.04	1.91	45.8	14.7	42.0	0.85	74	33	15	52	35.1
29	1.14	1.95	41.4	12.9	48.7	1.95	86.2	43	20	37	28.4
30	1.47	2.79	47.1	10.5	50.7	1.02	59.8	48	15	37	10.6
31	1.28	1.97	35.2	2.5	33.1	0.77	57.8	33	25	42	30.3
32	1.09	1.99	45.3	28.0	32.0	1.12	73.4	33	30	37	29.2
33	1.10	2.16	49.1	24.9	34.2	1.18	64.8	28	30	42	31.6
34	1.12	1.91	41.5	28.8	47.9	1.06	59.8	38	25	37	29.6
35	1.19	2.07	42.7	5.1	42.6	1.27	70	38	30	32	45.0
36	1.18	1.96	39.7	8.5	45.2	1.87	68.2	43	35	22	32.0
37	1.13	2.19	48.3	7.1	46.7	1.42	68	43	15	42	12.4
38	1.17	2.03	42.4	17.5	50.8	1.63	61.4	48	25	27	57.3

Sample no.	BD (Mg m^{-3})	PD (Mg m^{-3})	Porosity (%)	Moisture (%)	WHC (%)	MWD (mm)	WSA (%)	Clay (%)	Silt (%)	Sand (%)	Acid phos. Activity (µg nitro-phenol g^{-1} h^{-1})
39	1.16	1.99	41.6	6.4	42.5	0.96	65	38	20	42	26.0
40	0.90	2.03	55.8	13.0	46.0	2.03	75.4	43	10	47	47.4
41	1.17	2.18	46.2	6.6	36.4	1.02	68	33	15	52	24.6
42	1.22	1.96	37.8	5.9	46.9	1.00	71	43	20	37	27.9
43	1.04	2.12	51.2	7.0	42.5	1.03	61.2	38	20	42	25.5
44	1.02	2.07	50.9	11.6	53.7	1.41	71	43	15	42	26.4
45	1.02	2.04	50.0	15.4	43.4	0.84	59.8	38	15	47	65.3
46	1.10	1.97	44.0	10.3	37.1	0.94	64.4	33	20	47	37.9
47	0.98	2.12	53.6	12.2	42.1	1.73	79	38	20	42	60.4
48	1.14	2.15	47.0	12.4	39.9	1.09	66.4	38	30	32	12.8
49	1.46	2.07	29.4	14.8	47.1	2.10	82	43	15	42	49.2
50	1.15	2.09	45.2	6.2	33.6	0.92	56.4	33	10	57	45.1
51	1.18	2.26	47.7	6.2	47.8	1.55	75	43	10	47	43.5
52	0.99	2.19	54.8	12.8	49.3	1.92	74.2	43	25	32	18.6
53	1.01	1.98	49.1	13.4	55.8	1.68	72.7	48	25	27	39.3
54	1.15	2.00	42.3	15.7	54.5	1.97	86.8	53	20	27	35.6
55	1.19	2.23	46.5	13.9	37.5	0.98	61.6	33	20	47	16.3
56	1.02	2.03	49.7	11.4	33.9	0.81	65	33	30	37	49.8
57	0.97	2.16	55.2	16.2	41.7	0.92	69	38	30	32	43.9
58	1.10	2.33	52.6	8.7	39.9	0.99	72.6	38	20	42	11.9
59	1.18	2.25	47.6	9.7	53.3	1.11	65.8	48	20	32	18.5
60	1.18	2.31	48.9	12.7	51.7	0.81	60.8	48	25	27	17.3
61	1.08	2.23	51.4	4.7	44.5	1.82	75.6	43	20	37	44.0
62	1.33	2.01	34.0	7.3	43.0	1.38	74.2	43	10	47	27.5
63	1.24	2.12	41.5	8.0	57.7	1.68	70.6	53	25	22	14.7
64	1.36	1.91	28.8	7.3	34.9	0.89	61	33	20	47	3.5
65	1.22	2.11	42.3	13.3	49.8	1.33	69.4	48	20	32	4.6
66	1.12	2.20	49.0	6.4	32.6	1.02	72	28	30	42	15.3
67	1.11	2.18	49.1	9.4	50.7	1.08	66.6	43	15	42	21.0
68	1.34	2.34	42.8	11.6	61.5	1.67	73.2	63	10	27	14.1
69	1.15	2.22	48.4	6.2	45.2	1.15	69.4	38	30	32	75.2
70	1.06	2.28	53.4	8.4	38.4	0.90	67.2	28	30	42	21.2
71	1.12	2.22	49.5	6.6	41.6	0.64	63.2	33	15	52	15.7
72	1.13	2.03	44.3	11.6	46.3	0.67	65	38	10	52	14.5
73	1.21	2.20	45.0	6.4	46.2	0.95	62.4	43	25	32	12.2
74	1.01	2.05	50.5	5.1	38.6	0.96	70.2	33	20	47	4.5
75	1.06	2.18	51.4	6.8	48.0	2.00	77	43	25	32	16.5
76	1.17	2.18	46.1	4.3	40.0	1.57	67.8	38	20	42	32.4
77	1.15	2.22	48.3	4.4	52.1	1.59	78.6	53	20	27	28.0
78	1.17	2.10	44.3	3.0	49.9	1.41	73	48	20	32	37.2

APPENDIX III

Chemical properties of soil samples

Sample no.	pH	EC (dS m^{-1})	OC (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av. Ca (kg ha^{-1})	Av. Mg (kg ha^{-1})	Av. S (kg ha^{-1})	Av. B (kg ha^{-1})	RSQI (%)	LQI (kg m^{-2})
1	5.48	0.018	0.47	327.1	14.0	11.2	140	24	11.5	0.18	35.0	0.77
2	5.64	0.022	1.35	327.1	39.2	33.6	180	36	10	0.25	55.0	2.76
3	6.07	0.012	1.50	224.9	36.2	112	380	48	1.5	0.32	61.3	2.38
4	5.3	0.167	1.47	306.7	37.0	78.4	380	84	4	0.34	58.8	3.26
5	5.74	0.097	1.97	327.1	19.2	425.6	800	24	2	0.37	60.0	3.15
6	5.76	0.044	0.47	224.9	10.5	67.2	280	108	7	0.28	47.5	0.78
7	5.32	0.05	2.18	408.9	48.3	168	480	120	1.5	0.11	61.3	3.26
8	5.75	0.06	1.65	613.4	52.6	168	640	48	2	0.30	56.3	2.71
9	6.28	0.039	0.74	388.5	17.7	112	240	72	0.5	0.35	48.8	1.16
10	5.42	0.052	1.92	306.7	31.7	179.2	520	132	12.5	0.46	68.8	3.15
11	6.02	0.037	2.45	265.8	87.7	44.8	560	144	80	0.14	76.3	4.11
12	5.71	0.044	1.94	224.9	99.9	324.8	780	156	2.5	0.12	70.0	4.11
13	5.21	0.062	0.93	511.2	50.4	145.6	320	96	9	0.30	61.3	1.60
14	6.09	0.084	2.42	347.6	13.8	649.6	880	96	1	0.10	73.8	3.85
15	4.94	0.023	2.52	470.3	3.9	201.6	100	24	6.5	0.32	52.5	3.75
16	5.76	0.04	2.27	368.0	17.5	392	800	132	60.5	0.29	71.3	3.50
17	5.73	0.077	1.71	368.0	85.7	313.6	700	120	6	0.34	71.3	3.26
18	5.46	0.173	1.65	388.5	91.1	156.8	800	240	2	0.29	66.3	3.30
19	6.17	0.185	2.30	408.9	67.6	403.2	780	96	2.5	0.19	70.0	3.96
20	5.03	0.068	3.15	572.5	16.1	380.8	320	96	3	0.18	62.5	4.79
21	6.08	0.157	2.76	368.0	83.8	425.6	1800	324	12	0.26	77.5	5.28
22	6.17	0.124	2.54	654.3	53.6	548.8	980	192	7.5	0.30	73.8	4.77
23	5.69	0.04	0.93	408.9	22.2	145.6	680	204	6	0.19	70.0	1.82
24	5.35	0.031	1.79	347.6	53.0	201.6	620	72	1.5	0.30	62.5	3.26
25	5.66	0.056	1.47	347.6	87.4	448	620	156	6.5	0.15	67.5	2.78
26	5.65	0.029	1.68	245.4	76.5	145.6	520	132	4.5	0.16	71.3	3.63
27	6.12	0.037	0.51	265.8	10.3	179.2	400	72	4.5	0.14	60.0	0.87
28	5.58	0.054	2.42	245.4	13.6	459.2	700	144	5	0.11	77.5	3.75
29	6.41	0.052	1.91	306.7	82.1	369.6	1760	72	3	0.12	68.8	3.26
30	5.91	0.058	0.78	286.3	35.5	526.4	620	180	5	0.10	60.0	1.73
31	5.37	0.167	0.96	265.8	11.4	224	540	120	4.5	0.10	67.5	1.84
32	5.12	0.24	2.13	388.5	60.9	156.8	780	204	80	0.27	67.5	3.48
33	5.01	0.063	1.04	368.0	171.4	403.2	740	168	4.5	0.14	73.8	1.71
34	5.47	0.143	2.64	408.9	45.0	616	1100	84	6	0.14	62.5	4.42
35	6.46	0.094	2.06	408.9	23.1	504	1600	192	11	0.12	76.3	3.66
36	5.76	0.084	1.92	736.1	113.7	784	900	168	3	0.14	71.3	3.41
37	6.49	0.153	1.71	286.3	70.7	380.8	1600	96	2.5	0.15	63.8	2.91
38	5.18	0.3	1.94	490.7	267.7	246.4	920	144	23	0.12	68.8	3.40
39	5.74	0.12	2.22	388.5	120.0	515.2	1220	216	4	0.11	70.0	3.87
40	6.35	0.22	2.25	511.2	105.5	560	1460	204	4.5	0.12	77.5	3.03

Sam-ple no.	pH	EC (dS m^{-1})	OC (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})	Av. Ca (kg ha^{-1})	Av. Mg (kg ha^{-1})	Av. S (kg ha^{-1})	Av. B (kg ha^{-1})	RSQI (%)	LQI (kg m^{-2})
41	6.45	0.46	1.59	265.8	49.7	627.2	1560	228	1.5	0.13	72.5	2.80
42	4.83	0.061	1.67	327.1	6.5	89.6	360	48	3	0.14	61.3	3.04
43	5.72	0.033	1.32	265.8	2.2	246.4	940	84	6.5	0.25	65.0	2.05
44	6.4	0.183	2.27	245.4	95.4	324.8	1800	120	2	0.14	71.3	3.46
45	5.7	0.22	2.97	470.3	57.3	358.4	1420	204	3	0.11	75.0	4.54
46	5.85	0.24	2.75	511.2	16.2	313.6	1460	168	3.5	0.13	73.8	4.54
47	5.88	0.27	2.75	674.7	202.2	380.8	1200	168	28.5	0.40	81.3	4.05
48	4.69	0.109	2.75	347.6	43.3	313.6	420	168	6	0.18	63.8	4.69
49	4.8	0.14	1.88	286.3	14.4	100.8	440	96	8.5	0.14	70.0	4.11
50	5.53	0.23	1.89	265.8	18.9	280	1020	48	19	0.22	66.3	3.25
51	5.76	0.166	1.64	613.4	11.0	347.2	840	168	3	0.15	75.0	2.90
52	4.66	0.089	1.16	306.7	1.9	235.2	220	120	1	0.22	61.3	1.71
53	5.33	0.074	2.58	388.5	14.2	369.6	600	300	5.5	0.30	72.5	3.90
54	5.64	0.28	4.35	572.5	72.2	358.4	1860	324	8.5	0.14	75.0	7.53
55	5.36	0.073	1.11	286.3	3.4	358.4	320	120	66	0.13	65.0	1.99
56	5.51	0.21	5.16	388.5	123.4	112	1200	132	1.5	0.12	73.8	7.91
57	5.94	0.35	2.72	593.0	55.4	313.6	1520	192	12	0.48	73.8	3.94
58	5.37	0.058	0.65	224.9	25.2	224	340	48	5	0.11	52.5	1.07
59	6.48	0.2	2.04	368.0	155.3	716.8	240	48	47.5	0.30	57.5	3.61
60	5.43	0.068	1.32	327.1	6.3	190.4	620	108	6	0.16	62.5	2.34
61	5.52	0.173	3.99	306.7	28.4	235.2	1200	324	5.5	0.33	75.0	6.49
62	4.97	0.136	2.06	306.7	54.1	380.8	300	96	2.5	0.17	63.8	4.09
63	5.35	0.074	1.61	306.7	113.3	313.6	440	132	12	0.16	65.0	2.99
64	6.18	0.056	0.05	184.0	45.9	123.2	400	84	5	0.14	52.5	0.09
65	5.85	0.048	0.78	204.5	20.0	313.6	1800	312	3	0.17	60.0	1.43
66	6.48	0.25	2.27	245.4	169.5	560	1420	228	41	0.14	78.8	3.81
67	5.52	0.22	2.81	388.5	5.0	392	520	144	4	0.14	67.5	4.67
68	5.78	0.125	1.04	286.3	33.0	224	660	168	5.5	0.14	67.5	2.08
69	6.34	0.43	4.14	470.3	170.2	560	1360	300	5	0.14	80.0	7.11
70	6.4	0.141	2.67	449.8	32.3	168	1080	264	2.5	0.18	75.0	4.26
71	6.01	0.053	2.30	347.6	53.6	291.2	1060	144	3	0.14	72.5	3.86
72	5.41	0.153	2.07	408.9	1.5	201.6	440	120	3.5	0.10	58.8	3.51
73	4.78	0.097	1.05	265.8	57.9	504	460	84	15.5	0.31	56.3	1.91
74	5.43	0.093	2.48	449.8	9.3	190.4	500	108	3	0.19	65.0	3.77
75	5.7	0.094	2.90	388.5	45.7	100.8	400	60	2	0.10	66.3	4.60
76	5.21	0.092	1.07	265.8	39.2	257.6	560	84	2	0.17	66.3	1.88
77	5.62	0.076	1.86	286.3	40.5	179.2	620	132	6.5	0.25	71.3	3.20
78	5.34	0.33	3.02	408.9	41.3	504	820	168	8.5	0.40	72.5	5.29