ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF AEU 15 (NORTHERN HIGH HILLS) IN THRISSUR DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

By

MILI M.
(2018 – 11 – 024)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA
2020

ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF AEU 15 (NORTHERN HIGH HILLS) IN THRISSUR DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

By

MILI M.
(2018 – 11 – 024)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA
2020

DECLARATION

I, Mili M. (2018 - 11 - 024) hereby declare that this thesis entitled **"Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques"** is a bonafide record of research work done by me during the course of research and that the thesis has not been previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 11/11/2020

Mili M.

(2018- 11- 024)

CERTIFICATE

Certified that this thesis entitled **"Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques"** is a record of research work done independently by **Ms. Mili M.** (2018- 11- 024) under my guidance and supervision and that it has not been previously formed the basis for the award of any degree, diploma, associateship or fellowship to her.

11/11/2020

Vellanikkara

Date: 11/11/2020

Dr. Betty Bastin
Professor (Major Advisor)
Department of Soil Science and Agricultural Chemistry,
College of Horticulture ,
Vellanikkara, Thrissur

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Mili M. (2018-11-024)**, a candidate for the degree of **Master of Science in Agriculture**, with major field in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled **"Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques"** may be submitted by **Ms. Mili M. (2018-11-024)** in partial fulfillment of the requirement for the degree.

11/11/2020

Dr. Betty Bastin
(Major Advisor, Advisory Committee)
Professor
Department of Soil Science and
Agricultural Chemistry,
College of Horticulture, Vellanikkara

11/11/2020

Dr. Beena V. I.
(Member, Advisory Committee)
Assistant Professor and
Head -in- charge,
Radiotracer Laboratory
College of Horticulture, Vellanikkara

11.11.2020

Dr. Jayasree Sankar S.
(Member, Advisory Committee)
Professor and Head,
Department of Soil Science and
Agricultural Chemistry
College of Horticulture,
Vellanikkara

11-11-2020

Dr. Meera V. Menon
(Member, Advisory Committee)
Professor
Department of Agronomy
College of Horticulture,
Vellanikkara

ACKNOWLEDGEMENT

*First and foremost, I bow before the **Almighty**, for enlightening and blessing me with confidence, will power and courage to get through the difficult circumstances.*

*My words cannot express the deep sense of immeasurable gratitude and undoubtful indebtedness to **Dr.Betty Bastin**, Professor, Soil Science and Agricultutral Chemistry, College of Horticulture and chairperson of my advisory committee. With great respect and devotion, I wish to place my heartfelt thanks to her for the inspiring guidance, untiring interest, unstinted co-operation, esteemed advice, constructive criticism, valuable suggestion and immense help rendered by her during the investigation and preparation of the thesis. I am genuinely indebted to her for the constant encouragement and affectionate advice rendered to me.*

*I am thankful to **Dr. Jayasree Sankar S.,** Professor and Head**,** Department of Soil Science and Agricultural Chemistry, College of Horticulture and member of my advisory committee for her valuable suggestions and guidance .*

*I am deeply obliged to **Dr. Meera V. Menon.,** Professor, Department of Agronomy, College of Horticulture and member of my advisory committee for her unfailing support and enthusiasm.*

*I am forever grateful to **Dr.Beena V. I.**, Assistant Professor and Head in charge, Radio Tracer laboratory, College of Horticulture, Vellannikkara for her valuable help and guidance rendered.*

*I express my sincere gratitude to **Dr. Durga Devi,** Professor, Department of Soil Science and Agricultural Chemistry, College of Horticulture.*

*I am deeply indebted to **Dr. Rajalekshmi., Dr. Divya Vijayan,** and **Dr. Smitha John**, Assistant Professors in Department of Soil Science and Agricultural Chemistry, College of Horticulture for their valuable suggestions and support.*

*I also extend my gratitude to **Dr. T. Girija**, Professor and Head, Dept. of Plant Physiology and **Dr. K, Surendragopal**, Professor and Head, Dept. of Agricultural Microbiology.*

*I also thank **Mr. Satyan**, former Farm Superintendent, and the Agriculture Officers ; **Mr.Joseph John Therattil, Dr. Swapna S., Mrs. Sruthy and Mr. Vinod** for their kind help during my research work.*

*I take this opportunity to extend my gratitude to **Dr. A. T. Francies,** Librarian of the KAU Central Library.*

*I would like to acknowledge the help extended by each one of the non-teaching staff members, especially **Vijithra chechi, Vinitha chechi, Jayalakshmi chechi, Athira chechi, Sheela chechi, Sheena chechi, Jolly chechi, Sam chettan** and **Eldo chettan.** I also thank **Joy chettan, Sasi chettan and Praseetha chechi** for their help.*

*More personally I am thankful forever to all my loving friends **Milu Herbert**, **Gayathri B. R., Roshin Mariam George, Femina K., Sreekutty M.R., Aswathy Peethambaran, Shivadarsanapriya** and **Rashida V. K. and Laksmi Muralikrishna.** I also thank my dear colleagues **Gadha V. P., Safnathmol P., Neha Unni and Riaj Rahman** for their cooperation and support. I also extend my gratitude to my dear juniors **Anagha, Drisya, Aysha, Anju, Sreelakshmi, Afeefa and Najiya** for their sincere love and support. I also thank my dear seniors **Anusree, Amritha K., Amritha K. K., Roshni, Soniya, Nithin, Purandar, Anna, Merlin, Raji** and **Aparna** for their support.*

*I extend my heartlful gratitude to my dear **Anisha chechi** for building confidence in me at various stages of my research work and motivating me to achieve bigger goals.*

*Words won't suffice to thank my dear **Sophia chechi** who had helped me at my difficult times and staying close to me during the course of my research work. I am thankful to **Mr. Aravind K.S.** of Students' Computer Club, College of Horticulture for rendering necessary help whenever needed. The award of KAU fellowship is thankfully acknowledged.*

Above all, with gratitude and affection, I recall the moral support, boundless affection, constant encouragement, and motivation of my father, mother and my dear cousins without which this endeavour would never have become a reality.

Mili M.

DEDICATED TO

Parents,

Family,

Teachers &

Friends

List of abbreviations

%	-	Per cent
° E	-	Degree East
° N	-	Degree North
µg	-	microgram
B	-	Boron
BD	-	Bulk density
° C	-	Degree Celsius
Ca	-	Calcium
cm	-	Centimeter
cmol kg^{-1}	-	centimole per kilogram
Cu	-	Copper
DHA	-	Dehydrogenase activity
dS	-	Deci Siemen
EC	-	Electrical conductivity
Fe	-	Iron
g^{-1}	-	Per gram
GIS	-	Geographical information system
GPS	-	Global Positioning System
ha^{-1}	-	Per hectare
kg	-	Kilogram

K	-	Potassium
Mg	-	Magnesium
$Mg\ m^{-3}$	-	Megagram per cubic metre
Mn	-	Manganese
N	-	Nitrogen
P	-	Phosphorus
pH	-	Hydrogen ion concentration
S	-	Sulphur
SD	-	Standard deviation
SE	-	Standard error
TPF	-	Triphenylformazan
TTC	-	Triphenyl tetrazolium chloride
Zn	-	Zinc

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

APPENDICES

Sl no.	Appendix
1	Questionnaire for post- flood survey of AEU 15 in Thrissur district
2	Geographical coordinates of locations of soil sampling sites in AEU 15 of Thrissur district
3	Soil fertility ratings for organic carbon, primary, secondary and micronutrients
4	Lime and fertilizer recommendations for different panchayats in AEU 15 of Thrissur district
5	Summary statistics of soil properties of AEU 15 in Thrissur district.
6	Comparison of pre flood and post flood soil characteristics of AEU 15
7	Rock type, soil mapping unit and description of major soils in AEU 15 of Thrissur district

INTRODUCTION

1. INTRODUCTION

The state of Kerala had faced an extreme flooding event in August 2018 which is regarded as the worst flood in 100 years (earlier in 1924), resulting in human deaths, displacement of lakhs of people and loss of cultivated lands and property. Kerala received 42 per cent more rainfall than the usual rainfall since the beginning of the monsoon season in June (2346.3) instead of the mean rainfall of 1649.55 mm which had led to the opening of thirty nine dams for the first time in the history of the state. This gave rise to landslides and changes in the course of many rivers in the state. Depositions of mud, sand, debris and organic matter and also their removal were noticed in several areas of the state affecting soil quality. Soil quality determines the agricultural productivity of an area.

The normal rainfall in Thrissur district from 01 June to 21 August is usually 1824.4 mm. The actual rainfall in Thrissur district was 2077.6 mm, that is, 14 per cent of excess rainfall was received (IMD, 2018). More than 50 per cent of the district was devastated by floods (KSBB, 2018). The main rivers in the district are Bharathapuzha, and its tributary Gayathripuzha, Karuvannur river and its tributaries, Manali and Kurumali river, Chalakudipuzha, Kecheri river (Wadakkanchery river), Periyar river and Puzhakkal puzha. The rivers flowing through AEU 15 of the district are Manali, Muply and Chimmini Gayathrippuzha.

The high hills are known for cultivation of export- oriented crops such as banana, coconut and arecanut, spice crops namely, nutmeg, pepper and ginger as well as commercial crop like rubber. Flash floods in mountainous areas create flood conditions, landslide induced dam failure and fall of rocks. This lead to immediate rise and fall of water levels and greater flow velocities which combine to produce large amounts of sediment transport in the hilly regions. Floods will have an adverse effect on their growth, reproduction, yield and quality (colour, flavour, shape, size of the produce). The impact of flood on crops depend on the type of crop, variety, stage of growth, height and duration of submergence, water stress tolerance, weather prevailing during and after floods, prevalence of soil borne diseases already in the field and recovery rate. The reasons for the adverse effects include erosional loss of topsoil, leaching loss of nutrients, increase in compactness of soil leading to poor aeration and root growth, oxygen deficiency (hypoxia or anoxia), development of soil acidity followed by unavailability of mineral nutrients, changes in microbial ecosystem and development of soil borne diseases.

Management based on AEUs helps in effective and sustainable land use which in turn enhances agricultural output (KAU, 2016). Agro-ecological unit 15 (AEU 15) represents the Northern High Hills which covers an area of 59,486 ha. It is characterized by long dry spells (4 months in a year), a tropical humid monsoon type climate with an average annual precipitation of 3459.5 mm and a mean annual temperature of 26.2^{o}C. The hilly terrains have deep, well drained clay soils rich in organic matter and are strongly acidic, low in bases whereas the valleys have deep, imperfectly drained acid clayey soils. While forests cover the higher slopes of AEU 15 of the district, plantation crops like nutmeg, pepper and ginger are cultivated depending on slope and elevation of the land area. Valleys are characterized by arecanut, coconut and banana with rice in a few patches.

Due to the floods, the spice industry of the state was adversely affected. Nutmeg was subjected to a heavy loss of 2,749 tonnes valued at Rs. 101.8 crores. Black pepper saw a production loss of 10,700 tonnes, area loss of 26,613 hectares resulting in an overall monetary loss of Rs. 402.7 crores. (Spices Board, 2019). A loss of 3500 coconut palms and 1,00,000 juvenile coconut palms accounted for a yield loss of 95.6 million nuts in coconut cultivation (CPCRI, 2019). Banana plantations in 5204 hectares of land was destroyed in the floods.

Soils in AEU 15 prior to floods had medium to high organic carbon percentage, slightly acidic to very strongly acidic pH, high available nitrogen, medium to high available phosphorus, low to medium available potassium. In case of secondary nutrients, 45 per cent of samples were sufficient in available calcium, 78 per cent deficient in available magnesium, 58 per cent sufficient in available sulphur, 94 per cent sufficient in copper and 90 per cent in zinc and 55 per cent deficient in boron (KSHIS, 2013). The floods have led to massive crop loss by causing an increase in soil bulk density, nutritional losses, development of acidity and disesases.

Soil quality of a particular area is measured by soil quality index (SQI). This requires a minimum dataset (MDS). A minimum data set (MDS) consists of physical, chemical and biological indicators. The use of MDS reduces the need for using a wide range of indicators to assess soil quality. Soil quality indexing is an easy way of ensuring whether soil quality is improving, stable, or declining (Masto *et al.*, 2008). Nutrient index is another method of assessing soil quality based on the range of content of nutrients in a particular area.

Therefore a comprehensive flood study based on Agroecological units, their soil quality assessment and mapping gains momentum in the current scenario. Since panchayats form the functional units of an agroecological unit, a panchayat-wise soil assessment and dissemination of first hand information to farmers through government agencies like Krishibhavans is of utmost importance. This would help to arrive at solutions/suggestions for solving soil fertility issues.

Soil quality assessment helps in assessing the changes that had taken place due to flooding which in turn will determine soil functioning and productivity. Productivity of a soil is significantly associated to the food security and hence the following study entitled “Assessment of soil quality in the post flood soils of AEU 15 (Northern High Hills) in Thrissur district of Kerala and to develop maps using GIS techniques” was undertaken to characterize soil properties of flood affected soils in AEU 15 of Thrissur district with the following objectives:

- To assess soil quality of post-flood soils of AEU 15 in Thrissur district of Kerala.
- To develop maps on soil characters and quality using GIS techniques
- To work out soil quality index (SQI)

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The devastating floods of 2018 had caused great damage to the soil environment. Soil fertility and productivity have been disturbed, which needs site specific investigation on different soil fertility parameters. Plant nutrition needs to be relooked into and revised based on the altered soil fertility status, and suitable location specific management practices should be recommended.

2.1 Characteristics of AEU 15 (Northern High Hills)

AEU 15 is characterized by long dry spells (4 months in a year). The climate is tropical humid monsoon type. The average annual precipitation is 3459.5 mm and the mean annual temperature is 26.2^{o}C. The AEU 15 comprises of 61 Panchayats spread over Thrissur, Palakkad, Malappuram, Wayanad, Kozhikode, Kannur and Kasaragod districts and covers 13.6 per cent of the state. The hilly terrains have deep, well drained clay soils. They are rich in organic matter, strongly acidic and low in bases. The valleys have deep, imperfectly drained acid clay soils (KAU, 2016).

There are seven agro-ecological subunits in AEU 15 viz., forests, denudational hills, laterite plateau, laterite terrain, laterite valley, Wayanad plateau : undulating uplands and Wayanad plateau: valley. This unit covers 59,486 ha of the district (19.64%).

Kalamkar, S.S. (2008) studied the problems and prospects in North Eastern hill region of India where the average cropping intensity of the region was 131.7 per cent (rice being the lead crop). But its productivity was low due to less coverage of irrigation. In those areas where the mountain terrain is an obstacle for normal irrigation practices, water harvesting mechanisms is essential.

According to Barah (2010), the over-emphasis on high value crops (HVC) endangers the cultivation of several critical crops for food security , exposes hill residents to extreme poverty because of untapped natural resources and scarcity of irrigation facility.

.

Wani and Mir (2010) observed that the land-based economy of cold arid North-West Himalaya of Ladakh revealed that soil in the area is sandy, skeletal, celestius, fridged, which is low in nitrogen, moderate in phosphorus and high in potassium and sufficient copper and manganese to support crop production. The ground water is saline and not fit for irrigation purposes.

Shah (2010) found that the inefficient financial management and lack of growth are the weaknesses encountered by the farmers cultivating strawberry in the Western Hilly Tracts of Maharashtra.

Hatai *et al*. (2010) evaluated the problems and prospects of pineapple marketing in West Garo Hills of Meghalaya and found that developed market infrastructures, direct and group marketing, establishment of modern marketing and processing units, market integration are needed for improving the overall efficiency of the marketing system in those hilly areas.

Pathania (2011) reported the changes in hill agriculture in Himachal Pradesh where small and fragmented land holdings, undulating topography and predominance of cultivation under rainfed conditions were the dominant features

Saraf *et al*. (2018) studied the economic analysis of saffron cultivation which is a high profit crop in Jammu and Kashmir and reported that the human labour caused the major cost component in its cultivation.

Aforesaid conditions expose the hill farmers to more risks due to climate change, erosion of agro-biodiversity affecting the livelihood and the rural economy at large. Therefore traditional as well as modern methods of conservation of natural resources such as land, water, flora and fauna assumes greater importance in this scenario and certain proactive and response methods must be planned and transmitted accordingly for disaster mitigation in the future.

2.2 Soil quality : concept development and evolution

The queries on soil quality among policy makers and scientists saw a rapid increase after the book entitled ‘Soil and Water Quality: An Agenda for Agriculture’ was published by National Academy of Sciences in 1993. Dr. L.P. Wilding , the president of the SSSA, appointed a committee of 14 members from all the divisions in the year 1994 to look into definition of soil quality, examine its underlying principle and justify it and also to identify those soil and plant attributes that would be useful for describing and evaluating soil quality.

2.2.1 Definition of soil quality (SQ)

Soil quality was hence defined as "the capacity (of soil) to function". Its improved version defines soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." which was similar to the definitions given by Larsen and Pierce (1991), Doran and Parkin (1994) and Acton and Gregorich (1995).

2.2.2 Evaluation of soil quality

Soil quality is perceived in two ways: (i) as an inherent or innate capacity of soil and (ii) as a condition or health of soil (Karlen *et al.*, 1997). For the second situation, soil quality is measured by comparing the current state of an indicator with known or existing desired values.. An infinite list of soil attributes need not be assessed to find out soil quality but only those parameters required for a particular soil function need to be assessed. The parameters used for assessing soil quality should possess the following properties : (i) it should influence the function for which the assessment is being made, (ii) it should be measurable against some definable standard and (iii) it should be sensitive enough to detect differences at the point scale in time and space

2.2.3 Indicators of soil quality

Soil quality indicators are those soil properties and processes that have the highest sensitivity to changes in soil. Soil quality is influenced by physical, chemical and biological indicators. Soil physical indicators include soil texture, bulk density, water holding capacity, porosity etc. Soil chemical indicators include pH, electrical conductivity, exchangeable acidity, organic carbon content, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc and boron.

2.2.4 The concept of Minimum Data Set (MDS)

The Minimum Data Set (MDS) used in the computation of soil quality index is a set of indicators that are a subset of Total Data Set (TDS). An MDS was prepared by identifying, analyzing and aggregating the key soil quality parameters followed by the selection of the best indicators by statistical tools such as PCA or Principal Component Analysis which is a very efficient data reduction technique. Principal Component Analysis helps to determine the principal components (Yu-Dong *et al.,* 2013) and the criteria used were eigen value greater than one and variance greater than 5 per cent (Andrews, 2002). Eigen values are regarded as a special set of scalars related to a linear system of matrix equations (Hoffman and Kunze, 1971).

2.2.5 Indicator scoring and computation of SQI

There are mainly three steps in calculating soil quality index which includes selection of desired indicators for computing MDS using PCA analysis, transformation of these indicators into dimensionless score values and using these scores to find out the soil quality index (Andrews *et al.*, 2002). The indicators were organised in accordance with the degree of importance as to whether a higher value was considered 'good' or 'bad' in terms of its function in soil.

There are two methods of scoring, namely linear and non-linear scoring method. In linear scoring method, the highest value of a parameter was given a score of one for a more is better function and the lowest value was given a score of one in case of a less is better function. In non- linear scoring method, a sigmoidal function was used for scoring (Tesfahunegn, 2014).

The non-linear scoring indices were chosen in this study as they represented soil function better than linear scoring indices because of their higher F values and coefficient of variance, which expressed their better differentiating ability of the SQI calculation (Yu *et al.*,2018). The following sigmoidal function was used for non linear scoring:

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

where S_{NL} is the non-linear score of the soil indicator, a is the maximum score of the function (here a = 1), X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation which is laid as −2.5 for a 'more is better' curve and 2.5 for a 'less is better' curve (Raiesi, 2017; Yu *et al*. 2018).

Soil quality was thus obtained from the following formula:

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

Where W_i is the weightage factor obtained from PCA and S_i is the indicator score.

As the value of soil quality index increased, so does the soil quality and thus the function. Further SQI was categorized into three classes by Singh *et al*. (2013) on his work based on landuse impact on soil quality as:

SQI <0.5 was categorized as low, 0.5–0.75 as medium and >0.75 as high SQI.

Xu *et al*. (2006), in his study on soil quality indices and their application, the SQI values were grouped into five grades as:

Low (V), Lower (IV), Middle (III), Higher (II), and High (I), with SQI values of 0–0.2, 0.2–0.4, 0.4–0.6, 0.6– 0.8 and 0.8–1 respectively.

2.3 Relative soil quality index

Soil quality index values as such cannot be used for predicting the fertility status of soils. Therefore another quantitative measure called relative soil quality index or RSQI was calculated using the following formula proposed by Karlen and Stott (1994) :

$$RSQI = \frac{SQI_{\text{computed}}}{SQI_{\text{theoretical maximum}}} \times 100$$

RSQI values were rated as low (RSQI <50%) , medium (RSQI = 50- 70%) and high (RSQI > 75%) (Appendix III).

2.4 Nutrient index (NI)

Nutrient index is a measure of nutrient supplying capacity of soils to plants (Parker *et al.*,1951; Shetty *et al.,* 2008; Pathak, 2010; Kumar *et al*, 2013). Based on samples in high, medium and low category , this index helps in measuring fertility status of soils .The following formula was used:

$$\text{Nutrient Index} = \{(1 \text{ x } L) + (2 \text{ X } M) + (3 \text{ X } H)\}/ N$$

where L is the number of samples in low category, M is the number of samples in medium category, H is the number of samples in high category and N is the total number of samples. Ramamurthy and Bajaj (1969) classified fertility of soils into three classes viz; if the NI < 1.67 - low fertility, NI is between 1.67 to 2.33 - medium fertility and NI> 2.33 - high fertility.

2.5 Use of GPS and GIS techniques in soil fertility appraisal

According to Joy and Lu (2004), GIS models were inexpensive and required only simple data which helped the local authorities in the developing countries to utilise these sophisticated techniques to use remote sensing as a tool for delineation of flood affected areas, assesss the intensity of damage (flood depth) due to floods and formulate efficient tactics for fighting the flood disasters.

Bastin *et al*. (2014) prepared GPS and GIS based model soil fertility maps of Kerala to provide precise fertilizer recommendations to the farmers of Kerala for the nine districts of the state.

Vishnu *et al*. (2018) commented that the evaluation of the Kerala floods 2018 using August 21 Sentinel-1A satellite imagery indicated a 90% increase in water cover owing to flooding.

According to Santhi *et al*. (2018) ,the global positioning system (GPS) and geographical information system (GIS) techniques have enabled soil fertility appraisal of Villupuram district in Tamil Nadu and enabled the preparation of district nutrient plan for various taluks. When a nutrient plan for a district is made, there would be a balanced nutrition to crops and optimization of yields in the area. The geo-referenced sites obtained using GPS would enable scientists to monitor the changes in soil fertility in the area thereby benefitting the scientists, policy makers and farmers.

2.6 Physical attributes of soil of the study area before floods

Physical properties are related to structural and morphological characteristics of soil such as bulk density, particle density, porosity, aggregate stability, soil texture, maximum water holding capacity etc.

2.6.1 Soil texture

Raghunath (2017) recorded that the soils of upper, middle and lower reaches of Potta watershed in Pazhayannur block of Thrissur district didn't show any variation in their texture. The mean sand content was 55.47%, silt content being 31.39% and clay content of 13.13% which makes it sandy loam in texture. The reason for the homogeneity in textural class in all the reaches would point out to a similar and even soil formation process from similar types of parent materials.

2.6.2 Bulk density

As per a watershed study conducted by Raghunath (2017) in Pazhayannur block of Thrissur, the different reaches of Potta watershed varied in their bulk densities with their mean values of 1.52, 1.51 and 1.53 Mg m^{-3} in the upper, middle and lower reaches respectively but the predominance of higher bulk densities in all the reaches seem to reach a value of 1.7 Mg m^{-3} which cause restriction of root development. The need for addition of adequate organic matter was suggested for such soils with higher bulk densities.

2.6.3 Particle density

The mean particle density values were 2.44, 2.46 and 2.49 Mg m^{-3} in the upper, middle and lower reaches of Potta watershed respectively. The reason for slight variation in particle density within and between reaches is due to difference in mineralogical composition and quantity of organic matter (Raghunath, 2017).

Schjønning *et al.* (2017) were of the opinion that clay particles which were enriched in secondary minerals possessed a higher particle density than quartz material dominant in the silt and especially the sand fraction. Particle density was found to be affected approximately equally (~0.022 – ~0.024 Mg m^{-3}) by a 10% unit change in clay content and a 1% unit change in SOM content.

Rühlmann *et al.* (2006) reported that particle density of soils decreased with increasing content of sand content. According to McBride *et al.* (2012), soil is most often regarded as a simple two-component system consisting of mineral (Dp1) and humic (Dp2) substances for particle density estimation.

Skjemstad *et al.* (1993) reported that degree of "physical protection" by the mineral fraction (i.e, clay and silt fractions) on the organic fraction may influence particle density as the SOM content increases and that up to 23% of SOM may be physically protected by the clay fraction, and 36% by the silt fraction

2.6.4 Water holding capacity

Only a slight variation in water holding capacities viz., 36.56 per cent, 39.38 per cent and 38.24 per cent of the three reaches (upper, middle and lower respectively) were noticed in a watershed survey conducted by Raghunath (2017) in Potta watershed of Pazhayannur block of Thrissur district. This slight variation may be due to differences in organic matter, silt and clay content between different sampling sites.

According to a study conducted in Arunachal Pradesh by Bordoloi *et al.* (2018), mean MWHC per cent decreases with the increase in altitude and increases with increase in organic matter content.

2.7 Chemical attributes of study area before floods

2.7.1 Soil pH

In a study conducted by Sujatha *et al*. (2013), about 6 per cent of the soils under AEU 15 (Northern High Hills) of Thrissur district came under the class of extremely acidic soils , 53% under strongly acidic soils , 33-34 per cent under moderately acidic and only 7-8% under neutral to alkaline soils.

According to Kumar *et al*. (2016) the soil pH of Thrissur district varied from 4.35 to 6.22 with a mean of 5.19 (highly acidic).

According to Kavitha (2017), crops such as coconut, paddy, banana and nutmeg in AEU 15 were found to be cultivated in soils with extreme acidic condition. In neutral to slightly alkaline soils, coconut, arecanut, banana and nutmeg were cultivated. Here coconut was cultivated in the pH range of 3.7- 7.5, arecanut at a pH range of 4.1 – 7.4, vegetables at a pH range of 5.3 -6.4, pepper at a pH of 5.8 – 5.9, banana at a pH range of 3.7- 7.5, nutmeg at a pH range of 3.7-7.4 and rubber at a pH range of 4.1-6.8.

As per a study conducted by Raghunath (2017) in Potta watershed of Pazhayannur block, there was significant difference in the mean pH values between different reaches viz., upper (4.21), middle (4.91) and lower (5.38) reaches. The lowest pH being observed in upper reaches of the watershed showed that much of the exchangeable bases were leached by runoff water during rains . Also the highest pH was recorded in the lower reaches due to deposition of these leached exchangeable bases at the lower planes.

In the case of soil reaction, 29.69 per cent of the area in Talappilly taluk of Pazhayannur panchayath belonged to very strongly acidic range, 32.53 % under strongly acidic range, 24.5% under medium acidic range and only 4.21 % of the area belonged to neutral to mildly alkaline range (Shyju and Kumaraswamy, 2019).

2.7.2 Electrical conductivity

Bastin *et al*. (2014) reported that mean EC values for Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 0.09, 0.07 and 0.07 dS m^{-1} respectively and were all non saline in nature.

According to Kumar *et al*. (2016) , the soil soluble salt content as measured by EC of Thrissur district ranged from 0.04 to 0.99 dS m^{-1} with a mean of 0.31 dS m^{-1} which was below optimal level for farming. The electrical conductivity showed a positive correlation with available iron and copper and negatively correlated with available Mg, K and Mn.

According to a GIS based soil fertility study conducted by Kavitha (2017), all the soils of AEU 15 belonged to non saline nature (EC<1 dS m^{-1}). It was also reported from AEU 15 that the electrical conductivity ranges in the place varied from 0.01 to 0.6 dS m^{-1} in coconut growing areas, 0.02 – 0.30 dS m^{-1} in arecanut plantations, 0.06-0.1 dS m^{-1} in vegetable cultivation areas, 0.04 – 0.09 dS m^{-1} in pepper growing areas, 0.01- 06 dS m^{-1} in both banana plantations and nutmeg gardens and 0.01- 0.30 dS m^{-1} in rubber plantations.

2.7.3 Organic carbon

Bastin *et al.* (2014) reported that mean organic carbon values for Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 0.69, 0.76 and 0.79 % respectively.

According to Kumar *et al.* (2016), not much difference in organic carbon content (%) between soils of different panchayats of Thrissur district were noted. Here the organic carbon content in soils ranged from 0.42 to 2.15 % with a mean of 1.11%.

Kavitha (2017) reported that the organic carbon content in AEU 15 in Thrissur district varied from 0.04% to 7.60% . Range of organic carbon content was as follows: 0.04 to 7.60% in coconut gardens, 0.20 to 7.60 % in arecanut gardens, 0.50-2.20% in vegetable gardens,1.00- 2.00% in pepper lands, 0.04- 4.40 % in banana plantations , 0.10- 7.60% in nutmeg plantations and 0.40- 4.30% in rubber plantations. High level of organic carbon was witnessed in 58% of the coconut gardens, 50% of vegetable gardens, 43% of nutmeg and 40% of banana plantations.

In a study conducted by Raghunath (2017) in Potta watershed of Pazhayannur block, the mean organic carbon status was higher in the middle reach (1.11%) and lower in upper reaches (0.56%). The low organic carbon status in the upper reach was attributed to the lack of dense vegetation, minimal addition of organic matter and other fertilizer amendments in the area whereas the presence of high mean organic carbon content in the middle reach is due to accumulation of nutrients due to soil erosion resulting from variation in slope between middle and upper reaches.

2.7.4 Available nitrogen

Sujatha *et al*. (2013) reported that the northern high hills (AEU 15) in Thrisuur district which was rich in organic matter supplied enough available nitrogen and there was no deficiency of nitrogen in those soils and only 6 per cent of the soils in AEU 15 were deficient in nitrogen which was negligible compared to other AEUs in the district such as northern coastal plain, northern central laterite, kole lands, pokkali lands, and southern high hills.

Bastin *et al*. (2014) reported that mean available nitrogen content of soils of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 551.47, 669.38 and 684 kg ha^{-1} respectively.

According to a recent study by Kavitha (2019), AEU 15 comprising of northern high hills, showed wide variation in available nitrogen contents in various agroecosystems under coconut (82- 2240 kg N ha^{-1}), arecanut (89- 2160 kg N ha^{-1}), vegetables (179- 896 kg N ha^{-1}), pepper (448-672 kg N ha^{-1}), banana (22- 2240 kg N ha^{-1}), nutmeg (44-2240 kg N ha^{-1}) and rubber (134- 2240 kg N ha^{-1}).

In Thalappilly taluk, to which Pazhayannur panchayath of AEU 15 belongs, it was reported that 8.19% of the taluk had a low range of available nitrogen, 41 % of the taluk had a medium range of available nitrogen and 24.12 % had higher range of available nitrogen (Shyju and Kumaraswamy, 2019).

2.7.5 Available phosphorus

AEU 15 recorded excess levels of available phosphorus and about 88 per cent of the soils recorded excess levels of available phosphorus in soils. This could have been due to excess application of phosphatic fertilizers in the AEU (Sujatha *et al*., 2013).

As per Kumar *et al*. (2016), the available phosphorus in Thrissur ranged from moderate to high with a mean of 92.60 kg ha^{-1}. Organic carbon showed a strong and positive correlation with P, K, and Zn.

According to Shyju and Ramaswamy (2017), the percentage distribution of available phosphorus in Thalapilly taluk is 20.33% in low , 20.96 % in medium and 32.78% in high category.

Raghunath (2017) reported in his soil and water quality study in Potta watershed that in Pazhayannur just as in the case of organic carbon and available nitrogen, the mean available phosphorus was also highest in the middle reaches (15.15 kg ha^{-1}) and lowest in the lower reach (8.26 kg ha^{-1}). The high phosphorus content in middle reaches was due to increased cultivation and dense vegetation cover compared to other reaches and thereby continuous application of phosphatic fertilizers mainly factamphos and litter decomposition respectively (adds organic phosphorus) in the area. The lower reaches witnessed lower content of available phosphorus due to high iron content which might have been responsible for their adsorption in soils.

Kavitha (2019) had observed that the available phosphorus content in the AEU 15 i.e, northern high hills, showed a wide variation within and between different agroecosystems with values ranging from 0.60- 748.5 kg ha^{-1} in coconut gardens, 2-608 kg ha^{-1} in arecanut gardens,1.30-111.3 kg ha^{-1} in vegetables, 53 -362 kg ha^{-1} in pepper, 1- 698 kg ha^{-1} in banana, 0.60 -748.5 kg ha^{-1} in nutmeg and 3- 532 kg ha^{-1} in rubber.

2.7.6 Available potassium

In case of available potassium content, 58% of AEU 15 had high levels of available potassium in their soils. About 32 % of the AEU 15 fell under moderate levels of available potassium. Only 10% of the soils in AEU 15 were found to be deficient in available potassium. The available potassium content ranged from 1 to 1494.1 kg ha^{-1} in AEU 15 before floods (Sujatha *et al*., 2013)**.**

Bastin *et al.* (2014) reported that mean available potassium contents of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 306.50, 375.84 and 353.03 kg ha^{-1} respectively**.**

Kumar *et al*. (2016) reported that the available K content in soils of Thrissur ranged from 79.4 to 473.8 kg ha^{-1} with a mean of 252 kg ha^{-1} and these results indicated that available K is deficient in the soils of Thrissur district**.**

Shyju and Ramaswamy (2017) reported that the percentage distribution of available potassium was 11.99 %, 36.41% and 25.67% in the low, medium and high category respectively in Thalappilly taluk of Thrissur.

According to Raghunath (2017), the lowest mean content of available potassium was found in the upper reach (100.98 kg ha^{-1}) of Potta watershed in Pazhayannur block due to erosion loss to the middle reach which lead to its accumulation in the middle reach and thus a higher content of available potassium in those areas. Also a higher organic matter content was observed in the middle reaches. This also might have contributed to the increased availability of available potassium.

As per research reports by Kavitha (2019), available potassium in northern high hills also witnessed a wide variation as in the case of nitrogen and phosphorus. It varied according to different agro-ecosystems as, 4.3- 1494.1 kg ha^{-1} in coconut gardens, 5- 1494 kg ha^{-1} in arecanut gardens, 193- 433 kg ha^{-1} in vegetable gardens , 147- 344 in pepper gardens, 4- 1275 kg ha^{-1} in banana, 41- 1276 kg ha^{-1} in nutmeg and 41- 886 kg ha^{-1} in rubber plantations.

2.7.7 Available calcium

As per research reports from Kumar *et al.* (2016), the mean available calcium contents in the soils of Thrissur district is 394 mg kg^{-1}, which is higher than the critical limit of 300 mg kg^{-1}. The median value was 363 mg kg^{-1}, which established that available Ca is sufficient in the district. Highly significant correlation between Ca and other elements were absent.

Raghunath (2017), in his study on soil and water quality noted that available calcium content ranged from 30.94 to 40.85 mg kg^{-1} in Potta watershed in Pazhayannur and concluded that available calcium was evidently deficient and no remarkable variation in available calcium was observed in upper, middle and lower reaches and might be due to inherently acidic nature of the soils in the area.

According to Kavitha (2019), very low content of calcium was noted in all agroecosystems in AEU 15 except that of vegetables and pepper. High calcium content in AEU 15 was noted in coconut agroecosystem with 1525 mg kg-1 and lowest was noted in nutmeg gardens (42 mg kg-1). The deficiency can be attributed to the acidic nature of soils since the acidity in Kerala soils is contributed mainly by the aluminum ions present in the soil and the inability of the calcium ions (Ca^{2+}) to neutralize the aluminum ions (Al^{3+}).

2.7.8 Available magnesium

About 79% of the soils in AEU 15 were deficient in available magnesium and 21 % of the soils in AEU 15 before floods were sufficient in available magnesium (Sujatha *et al.,* 2013).

As per a study conducted by Raghunath (2017), available magnesium was deficient in all the reaches of Potta watershed in Pazhayannur panchayat and it ranged from 29.50 to 43.20 mg kg^{-1} and it was attributed to the acidic nature of soils.

According to a study by Kavitha (2019), northern high hills possessed magnesium mainly in the low category (<120 mg kg^{-1}). During rainy season, leaching of magnesium during runoff, coupled with an acidic condition of the soils, resulted in a notable deficiency of magnesium in the soils.

2.7.9 Available sulphur

Reports from a study conducted by Sujatha *et al*. (2013) shows that available sulphur content ranged from 0.03 to 47.10 mg kg^{-1} and 43% of the AEU 15 were deficient in available sulphur content in their soils.

Raghunath (2017) found that available sulphur is sufficient in all the reaches of Pazhayannur panchayat and it ranged from 2.5 to 32.38 mg kg^{-1}. It might have been due to addition of sulphur containing agrochemicals.

A study conducted by Shyju and Kumaraswamy (2019), revealed that the availabile sulphur is rich in Talapilli taluk and it was distributed throughout the Taluk which was adequate for the plants and was deficient only in southeast of the Taluk only in a minor proportion.

2.7.10. Available iron

Bastin *et al*. (2014) reported that the mean available iron content of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 54.75, 68.11 and 78.59 mg kg^{-1} respectively.

According to Kumar *et al*. (2016), the mean available iron content in the soils of Thrissur district ranged from 3.0 to 595.4 mg kg^{-1} with a mean value of 89.4 mg kg^{-1}.

In a soil and water quality study conducted by Raghunath (2017), eventhough low concentrations of iron were present in the middle (17.33 mg kg^{-1}) and lower reaches (13.74 mg kg^{-1}), the soils were sufficient in available iron owing to the presence of tropical lateritic soils which accumulate ions during the laterisation process. The reason for the low concentrations in middle and lower reaches as compared to the upper reach might be due to insoluble iron oxides and iron phosphate formation in these reaches

As per a spatial variation study by Kavitha *et al*. (2019), about 99.96% (3028.84 km^2) of Thrissur district showed adequate status of available iron and its deficiency was confined to only 0.04% of Thrissur district (1.16 km^2) .

It was also found that the available iron content varied from 0.1 - 675 mg kg^{-1} mg kg^{-1} in Thrissur district. Coconut, arecanut and nutmeg agroecosysytems showed deficiency of available iron in AEU 15 and it may be due to relatively increased soil pH due to application of liming materials (Kavitha, 2019).

2.7.11 Available manganese

Bastin *et al.* (2014) reported that mean available manganese contents of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 33.06, 48.69 and 23.87 mg kg^{-1} respectively.

According to Kumar *et al.* (2016), the available manganese content in the soils of Thrissur district were sufficient and it ranged from 5.8 to 54.0 mg kg^{-1} with a mean value of 22.1 mg kg^{-1}.

As per a watershed study in Pazhayannur panchayat by Raghunath (2017), the highest mean was recorded in the upper reach (42.5 mg kg^{-1}) and all the reaches recorded very high manganese well above the critical range and the reason attributed to this are chelation of manganese with organic compounds released during organic matter decomposition.

According to Kavitha *et al*. (2019), a very high level of available manganese was observed in 93.98% i.e 2847.54 km^2 of Thrissur district. Its defciency was negligible (6%) in the district (182.46 km^2).

2.7.12 Available zinc

With respect to available zinc, AEU 15 had sufficient levels . Only about 15 % of the soils in AEU 15 were deficient in available zinc (Sujatha *et al.* 2013).

Bastin *et al*. (2014) reported that mean available zinc contents of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 2.13, 2.70 and 4.07 mg kg^{-1} respectively.

According to Kumar *et al*. (2016), the available zinc content in the soils of Thrissur district were sufficient and it ranged from 0.9 to 10.9 mg kg^{-1} with a mean value of 5.4 mg kg^{-1}.

Kavitha *et al*. (2017) established that the soils with optimum range of available zinc in Thrissur district were spatially distributed over a larger area (95.2%) of about 2884.13 km^2 and the defciency of Zn was spread over the rest 4.8 % of the district, covering an area of 145.87 km^2 .

Sujatha *et al*. (2013) and Kavitha and Sujatha (2015) attributed the sufficiency status of zinc in Thrissur district due to its presence as a contaminant in phosphatic fertilizers which is applied luxuriously in the area.

Raghunath (2017) , in his soil and water quality study in Potta watershed of Pazhayannur panchayth reported that all the reaches were sufficient in terms of available zinc content in the soils. But a lower mean zinc content was observed in the middle (3.16 mg kg^{-1}) and lower reaches (3.52 mg kg^{-1}) as compared to the upper reach (6.21 mg kg^{-1}) due to its uptake by rice and vegetables where they are cultivated intensively.

2.7.13 Available copper

Majority of the soils of AEU 15 had sufficient levels of available copper and a mere 10% of the soils were deficient in copper (Sujatha *et al.* 2013)

As per Sureshkumar *et al*. (2013), flooded conditions lead to the formation of insoluble CuS due to the reduction of SO_4^{2-} to sulphide.

Bastin *et al*. (2014) reported that mean available copper content of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 4.75, 4.10 and 4.05 mg kg^{-1} respectively.

Kavitha *et al*. (2019), in their study regarding spatial variation in soil micronutrients as influenced by agro ecological conditions in a tropical humid region deduced that 85.20 % of Thrissur extending to about 2580.41 km^2 of area were found to contain high levels of copper. The defciency of copper was confned to about 14.8% of the district (449.59 km^2).

According to Kumar *et al*. (2016), the available copper content in the soils of Thrissur district were sufficient and it ranged from 0.3 to 12.5 mg kg^{-1} with a mean value of 3.9 mg kg^{-1}**.**

According to a GIS based fertility mapping study conducted by Kavitha (2017) in Thrissur district of Kerala, available copper was found to be optimum and the reason was thus ascribed to the use of copper containing fungicides for controlling fungal diseases and its adsorption on organic matter.

Raghunath (2017) established that all the samples were sufficient in available copper content in the soils of three reaches in Potta watershed of pazhayannur panchayat and their availability was rather high and the highest value (11.3 mg kg^{-1}) being recorded in the lower reach. This sufficiency can be attributed to the continuous application of organic matter and copper containing pesticides in the area.

Kavitha (2019) reported that the copper content in soils ranged between 0.01 – 54 mg kg^{-1} in Thrissur district. Copper deficiency was noted in all agroecosystems of AEU 15 except that of vegetable gardens. This deficiency of available copper is usually witnessed in organic matter rich soils due to its chelating action of organic matter with copper ions.

2.7.14 Available boron

Truog (1945) showed that the availability of boron increases upto pH 5, remains constant upto 7 and decreases beyond this pH i.e. upto 8.8 and finally increases above 8.8.

According to Sujatha *et al*. (2013), all the soils were deficient in boron in AEU 15. The reason might be due to the fact that boron is present in the soil as boric acid and is non ionic in nature, they get leached away easily and are found deficient in areas of high rainfall (Marshner , 1995) and it was also established that high levels of calcium in soils also aggravated boron deficiency (Eck and Campbell, 1962). Organic matter held a major portion of total boron in the soil by tightly binding in plant derived compounds (Bragg and Perk, 1962)

Bastin *et al*. (2014) reported that mean available boron contents of Thrissur, Thalappilly and Mukundapuram taluks of Thrissur district were 1.89, 2.27 and 2.70 mg kg^{-1} respectively.

According to Kumar *et al*. (2016), the available boron content in the soils of Thrissur district were deficient and it ranged from 0.03 to 2.20 mg kg^{-1} with a mean value of 0.60 mg kg^{-1}.

2.8 Soil quality as affected by floods

Both vegetative and reproductive phases of a crop are threatened by waterlogging (Kumutha *et al.,* 2008; Irfan *et al*., 2010; Shabala, 2011).

Soil quality is undoubtedly affected by floods, either positively or negatively regarding the growth of crops. Flooding occurs when either the ground water reaches the soil surface or there is an excessive rain coupled with impermeable soils. The soil characteristics after flooding would depend on the quality of flood water i.e, bases and salt-rich water (Tabaoga , 1988). The stagnant water create anaerobic situation for a considerable amount of time and this would create several physico- chemical changes in the soil as would be discussed later.

Khabaz-Saberi and Rengel (2010) and Shabala (2011) were of the opinion that surplus water in flooded soils caused a sharp decline in soil redox potential, resulting in significant changes to the soil elemental profile thereby leading to a high partial pressure of CO_2 in the root zone, resulting in serious consequences for root growth and metabolism (Shabala, 2011).

According to Kumutha *et al*. (2008) and Irfan *et al*. (2010) , waterlogging causes a situation in which there is deficiency of oxygen due to slow diffusion of oxygen from atmosphere to water and a faster rate of oxygen consumption by the micro organisms in the soil. Since roots and rhizomes are essentially aerobic organs, the cessation of aerobic respiration as a consequence of waterlogging results in a drop in energy level status of root cells, and uptake and transport of ions by the plants decline, which is fatal.

Kirk (2004) was of the opinion that there occurs a sequential redox reactions of elements (reduction and oxidation) in saturated soil conditions. Ponnamperuma (1972) and Patrick and Jugsujinda (1992) revealed this thermodynamic sequence to be in the following order: oxygen, nitrate, manganese, iron, sulphur, and then organic substrates .

2.9 Status of physical attributes of soil after floods

According to Rowell (1981), the redox conditions developed during short term flooding affected the aggregate structure of soil and stability ratio reduced from 0.771 to 0.716 in a span of three days and to 0.703 in a span of 14 days.

Sumner (1992) and LeBissonnais (1996) observed that an increased soil moisture is found to increase swelling in soils. Swelling occurs due to contact of the soil organic matter or expandable 2:1 clay minerals, such as smectites with water. The water that is trapped in the structure of the organic matter or clay interlayers leads to the expansion of soil particles causing the aggregates to breakdown.

Truman *et al*. (1990) noted that during the aggregate breakdown process ,the slaking mechanism occurs in the initial stages of saturation where the soil is wetted first and the trapped air in it gets compressed. When the initial soil moisture increases and the amount of air entrapped decreases ,the slaking process becomes less important.

Tortuosity of pore interspaces, and thus porosity, decreases with increased CEC under reducing conditions (Kirk, 2004) .

Another study conducted in US Midwest, the soils which were under ponded conditions during rainy season developed reducing conditions due to depletion of oxygen which affected the chemical equilibrium of the soil and thus the soil aggregation which in turn affected crop production and yield. It was found that an approximate 20% decrease in aggregation was noticed in a period of two weeks. This was due to changes taking place in the amount of redox sensitive elements, alkaline metals, and dissolved organic carbon under reducing conditions (Alfredo *et al*., 2009).

According to a post flood study conducted by Kalashetty *et al.* (2012) the bulk density, texture and water holding capacity were observed to be the same in majority of the study area after floods.

Porosity of sandy surface soils ranged from 35% to 50%, whereas finer textured soil typically ranged from 40% to 60% . Compact subsoils had as little as 25%–30% total pore space (Hao *et al.* 2019).

2.10 Status of chemical attributes of soil after floods

2.10.1 Soil pH

As per Ponnamperuma, (1972), reducing conditions in flooded soils tended to bring the pH to near neutral range, i.e, when acidic soils were flooded, the pH of the soil increased to pH 7 which led to changes in the physicochemical characteristics of the soil.

Suarez *et al.* (1984) opined that the strength of bonding between iron and aluminium (hydr)oxides to clay particles decreased when pH rose above PZC (Point of zero charge) leading to dispersion of soil.

According to Inglett *et al.* (2005), pH in most soils reached a neutral point under submerged conditions with an increase in pH in acidic soils and decrease in pH in alkaline soils.

As per a study conducted by Kalashetty *et al.* (2012) on flood effects on soil properties by Krishna river in Karnataka, the pH of the soil was found to diminish from 8.60 to 8.15 due to washing away of bases by floodwater.

According to a post flood study by Akpoveta *et al.* (2014) on the effect of flooding on soil quality in Nigeria, the average pH values were found to be 7.10 and 6.70 for soil samples obtained from farmlands in three places as opposed to a pH of 7.8 for control soil from a farmland which accounted for a reduction of 14% and 9% in pH respectively. Thus the pH was found to decrease due to flooding causing soil acidity.

2.10.2 Electrical conductivity

In a study conducted by Alfredo *et al.* (2009) in flooded soils, EC values showed an increase regardless of the cultivation of soil, the greatest increase being observed for the uncultivated soils. The average EC observed in uncultivated soil was 17.07 $\mu S\ m^{-1}$ after a flood, whereas it was 9.11 $\mu S\ m^{-1}$ for the cultivated soils for an incubation period of two weeks.

Kalashetty *et al.* (2012) discovered that the electrical conductivity increased from 0.68 to 1.14 $dS\ m^{-1}$ in flooded lands in cultivated areas in Bhagalkot district in Karnataka and it might be due to the deposition of total dissolved solids (TDS).

According to a post flood study by Akpoveta *et al.* (2014) on the effect of flooding on soil quality in Nigeria, electrical conductivity values for the control soil was recorded as 73.2 µS/cm, while the farmlands in Onitsha and Asaba which are flood hit were found to be 140.8 µS/cm and 122.8 µS/cm respectively, accounting for a 92% and 54% increase respectively and its reason was attributed to the intrusion of salts, ions and total dissolved solids carried by the flood waters.

2.10.3 Organic carbon

According to Alfredo *et al.* (2009), the uncultivated soils showed a higher (0.67- 0.90 mg C kg^{-1}) concentrations of the dissolved organic carbon (DOC) with incubation time, whereas it remained low (0.1- 0.56 mg C kg^{-1}) and relatively unchanged in cultivated soils. The cultivated soils showed an increased molecular weight of dissolved organic molecules**.**

According to Saint-Laurent (2016), the average total organic carbon for the surface soil (0–20 cm in depth) in the frequent flood zone was 1.74%, in moderate flood zones was 3.34% whereas it was 3.54% for the no-flood zone region of southern Quebec.

According to Kalashetty (2012), the organic carbon content increased from 0.60 to 0.74 % after river Krishna floods in Bhagalkot.

The organic carbon content decreased from 2.5% to 2.3% in upstream land, 1.6% to 1.7% in midstream and increased from 1.2% to 1.4% in downstream after floods (Mungai *et al*.,2011).

2.10.4 Available nitrogen

Unger *et al*. (2009), in their soil flooding studies found that the concentration of soil nitrate nitrogen decreased from 4.01 to 3.22 mg kg^{-1} and ammoniacal nitrogen had increased from 5.47 to 6.90 mg kg^{-1} in a period of five week floodin which was due to three nitrogen transformations occuring during flooding viz; ammonification, nitrate reduction and denitrification. Nitrate nitrogen which is a mobile form of nitrogen can also be leached from the system under flooded situations**.**

According to a flood study conducted by Alfredo *et al*. (2009), flooding of soils have significantly lead to a change in concentration of ammoniacal nitrogen and nitrate nitrogen of soil and thus influenced the accumulations of N in plant tissues.

As per a research study by Kalashetty *et al*. (2012) the nitrogen content decreased from 225 to 134 kg ha^{-1} in 0-20 cm of soil after the floods and the reasons attributed to this phenomenon are the dissolution of nitrate in the flood waters and its removal with the flood waters and denitrification of nitrates due to anaerobic conditions that prevailed during the floods. The high decomposable carbon content in the existing vegetation in the field coupled with the anoxic conditions might have set off the process of denitrification.

According to Sujatha *et al.* (2013), biological transformations of N is very much restricted in strongly acidic and flooded conditions and this explains the low levels of nitrogen.

2.10.5 Available phosphorus

Waterlogging significantly decreased soil phosphatase activity resulting in decreased soil available P content and thus the amount of P accumulation in the plants (Alfredo *et al*. 2009).

Kalashetty *et al*. (2012) reported that a post flood analysis of a cultivated area in Baghalkot, Karnataka showed that the available phosphorus content in the soils decreased from 21.8 to 11.8 kg ha^{-1} in 0-20 cm of soil after the floods and might have been due to the dissolution of applied fertilizers which are stored in the soil.

The water soluble phosphate content of soil increased from 2.4ppm to 4.2 ppm in a 2 week fand 6- week flooding period respectively (Ponnamperuma, 1972).

The dissolved reactive phosphorus decreased from 11.88 mg/L in and 21.92 mg/L in vegetable growing soil and wheat growing soil, respectively to 1.39 mg/L and 3.28 mg/L, respectively 35 days after flooding (Tian *et al*, 2017).

2.10.6 Available potassium

According to Mungai *et al*. (2011), extractable potassium decreased from 332 to 134 mg kg^{-1} in 0-20 cm of soil after a flooding period of 28 days in Lake Victoria basin South Africa

According to Kalashetty *et al*. (2012), the quantity of available potassium witnessed an increase after the floods from 348 to 377 kg ha^{-1} in flooded areas and the reason was attributed to the saturation of the soil which might have lead to the widening of smectitic clay minerals and release of previously fixed potassium and also due to dissolution of the stored fertilizers within the flood water.

According to Chris *et al*. (2013), the exchangeable potassium did not change in response to 30 days of inundation in soils under study.

2.10.8 Status of available secondary nutrients after floods

A loss of Ca and Mg from the exchange sites of clays during flooding may decrease clay flocculation, thereby increases the aggregate instability (Heil and Sposito, 1993).

Kalashetty *et al*. (2012), reported that the floods in Bhagalkot in 2009 had caused an increase in the concentrations of available calcium from 0.98 to 1.1%, magnesium from 0.37 to 0.56% and sulphur from 16 to 21.5 ppm in the soils.

A marked increase in calcium (from 208 to 239 mg kg^{-1}) and magnesium (17.2 to 19.6 mg kg^{-1}) concentration were observed during the flooded period in floodwater in the Nemunas and Minija lowlands during January in 2007 and 2008 (Katutis, 2015).

2.10.9 Status of available micronutrients after floods

In a research finding by Alfredo *et al*. (2009), during submergence, the concentrations of Fe^{2+} and total soluble Mn increased and the greatest increase was observed for the uncultivated soils after three days of incubation and it was observed that the concentrations of Mn in the uncultivated soils were always higher than Fe^{2+} for the same incubation period. With time, the solution concentrations of Ca and Mg also increased and this phenomenon was also confirmed by the increase in the EC throughout the incubation period .

According to Kalashetty *et al*. (2012), after the Rabi floods of 2009 in Bhagalkot, the available manganese and boron were found to be below the limits, where as the quantity of available iron, zinc and copper have surpassed the legal limits because of the sludge disposal legacy for cultivated soils.

2.11 Biological attributes of soil as affected by floods

2.11.1 Dehydrogenase activity

Soil dehydrogenases serve as an indicator of soil microbial activity and are regarded as one among the most important enzymes in all other soil enzymes

(Quilchano and Marañon, 2002) and they occur intracellularly in the cells of all living microbes (Yuan & Yue, 2012).

Trevors (1984) and Subhani (2001) reported that the concentration of DHA is higher in flooded (anaerobic) soils than aerobically incubated soils. It was reported that DHA in the flooded soil was found to be between 1985.48 and 2300 µg TPF g^{-1} soil in flooded soil which is comparatively higher than non flooded soil.

Anaerobic microbes produced the most dehydrogenases and active dehydrogenases utilised both oxygen and other compounds as terminal electron acceptors. DHA present a clear picture of the metabolic ability of the soil and its activity is considered to be proportional to the biomass of the microorganisms in soil (Brzezińska *et al.* 2001).

Subhani *et al*. (2001) were of the opinion that any compound that alters the number or activity of microorganisms, could affect soil biochemical properties, and hence the soil fertility and plant growth .

Dehydrogenases were not found extracellular in the soil. They serve an important role in oxidation of organic matter by transferring hydrogen from organic substrates to inorganic ones (Zhang *et al*. 2010). Dehydrogenases were found to be strongly associated with microbial oxidoreduction processes (Moeskops *et al*. 2010).

Zhang *et al*. (2010) reported that DHA are highly related with microbial biomass (MB), which in turn affected the decomposition of organic matter and the release of $CaCO_3$.

During submergence, local anaerobic microsites were formed due to oxygen deficiency which enhanced the growth of anaerobic bacteria and dehydrogenase activity (Wolińska and Stępniewska, 2011).

Soil quality assessment encompassing soil's physical, chemical and biological properties have been analysed by various researchers as mentioned above, but quality assessment of soils in terms of soil quality index is lacking in our state. Studies on the key parameters constituting MDS and their impact on soil quality need to be looked into. Agro ecological unit-based soil quality assessment in the context of natural calamities, especially that of floods needs to be prioritized and explored. The research on the effect of flood on micronutrients as well as heavy metals are also scarce. Only few studies on impact of floods on soil quality had been carried out in our country. Works on physical properties namely bulk density, particle density, soil aeration and water holding capacity as affected by floods need greater attention as the texture and structure of soil gets altered depending on the different factors affecting flood. Post flood soil fertility mapping adopting GPS- GIS techniques help in regular monitoring of soil quality in flood prone areas. Correlation studies on physical, chemical and biological properties of soils before and after floods need to be thoroughly investigated. Cropping system based soil fertility studies consequent to floods are also important. Research on flood and landslide on soil quality in hilly areas on soil physical properties and soil mineral composition also deserve attention. It helps in regular monitoring of soil quality in flood prone areas. Changes in the microbial ecosystem following floods will throw light on soil functioning.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled 'Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques' investigates the post flood effects on soil properties and the relative changes due to August floods of 2018 in different locations of he study area of Northern High Hills of Thrissur district.

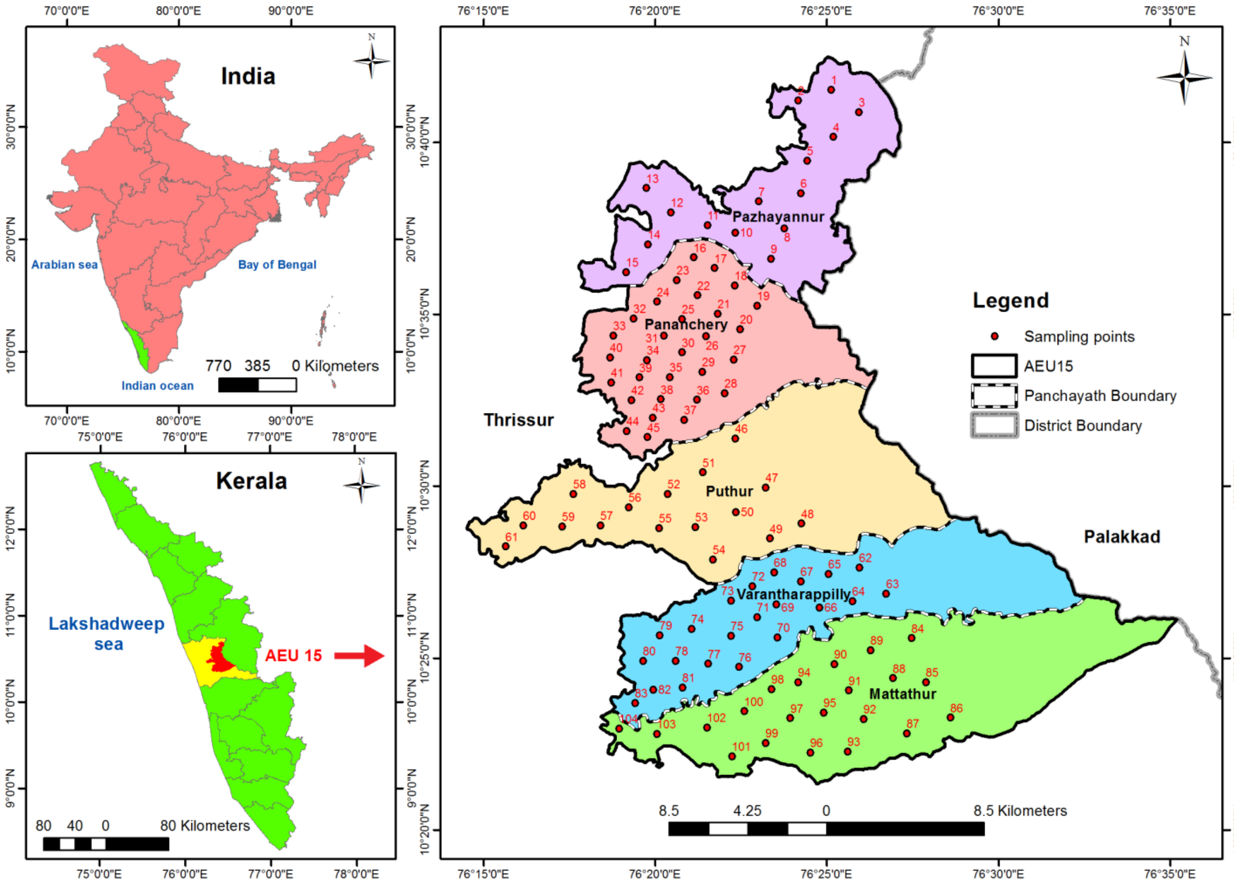
3 .1 Details of the location

AEU 15 (Northern High Hills) of Thrissur district comprises of 5 panchayats extending over 59,486 ha covering 19.64% of the district. The current study was aimed to assess soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and map them using GIS techniques. The following panchayats of Thrissur district under AEU 15 were studied viz; Pazhayannur Pananchery, Puthur, Varantharappilly and Mattathur. The locations of the sites from which soils were sampled using GPS are given in Appendix –I.

Table 3.1 Details of locations and soil samples collected from AEU 15 of Thrissur district

Taluk	Block	Grama Panchayat	Area of the panchayat (km^2)	No. of samples	Range of altitude (m)
Thalapally	Pazhayannur	Pazhayannur	59.03	15	51.0- 81.5
Thrissur	Ollukkara	Pananchery	141.71	30	15.7- 35.4
		Puthur	79.07	16	9.5 - 20.8
Mukundapuram	Kodakara	Mattathur	102.82	21	10.6 -27.4
		Varantharappilly	103.11	22	8.5– 22. 6

Fig 3.1 Location of sampling points in the study area



3.1.1 Climate

The climate of AEU 15 is characterized by tropical humid monsoon type i.e, humid to perhumid. The mean annual temperature is 26.2°C. May is found to be the hottest month with a temperature of 28°C. January is found to be comparatively cold (24 °C). The average annual precipitation is 3459.5 mm with a range of 1911 mm to 4965 mm. A subtropical humid climate is experienced (<18 °C for many months in a year) at elevations greater than 1500 m.

3.1.2 Topography

AEU 15 is dominated by steeply sloping hills and intervening narrow valleys. Arecanut, coconut, banana and rice in few patches are cultivated in the valleys. Plantation crops like coffee, rubber, tea and spices are cultivated in the hills. About 65% of the land area is put to agricultural use.

3.1.3 Soil characteristics

Hill slopes of AEU 15 have moderately deep to deep well drained clay soils. They are rich in organic matter, strongly acidic in nature and low in bases. The soils of the valley are characterized by deep and imperfectly drained clayey soils. (KAU, 2016). In AEU 15 of Thrissur district, Painkulam and Kozhukkully series are identified (SSOA, 2007). Rock type, soil mapping unit and description of major soils in AEU 15 of Thrissur district are given in Appendix VII (KSLUB, 2014).

3.2 Details of the study

The study comprised of four parts:

3.2.1. Survey, collection and characterization of soil

The soil samples were collected after the survey during the period between 24 September 2019 and 11 October 2019.

The survey was conducted (Appendix I) to identify the flood affected areas of AEU 15 in Thrissur district by visiting Krishi Bhavans of Pazhayannur Pananchery, Puthur and Varantharappilly and Mattathur panchayats.

After consulting with Agricultural officers in the five Krishibhavans in AEU 15 of Thrissur district, the flood affected areas were identified. Also, informal group discussions involving farmers, farmer groups and members from local bodies were conducted**.** Soil samples from flooded areas of the above said panchayats containing 5 composite samples from each site were collected. The number of samples collected were proportionate to the area (Table 3.1) of panchayats. Thus 104 soil samples were collected from different sites .The samples were collected in polythene bags and were labelled and geographic coordinates (latitude and longitude) of the sampling sites were recorded using a GPS device (Appendix II). The soil samples were characterized for physical, chemical and biological properties in the laboratory after drying and processing. The standard procedures adopted for analyses are given in Tables 3.2, 3.3 and 3.4. and the observations of following parameters were made:

3.2.1.1 Physical attributes

a. Bulk density
b. Particle density
c. Maximum water holding capacity
d. Porosity
e. Soil moisture content

3.2.1.2 Chemical attributes

a. pH
b. Electrical conductivity
c. Organic carbon
d. Exchangeable acidity
e. Available macronutrients : Available nitrogen, phosphorus and potassium

f. Available secondary nutrients: Available calcium, magnesium and sulphur

g. Available micronutrients : Available iron, manganese, copper. zinc and boron

3.2.1.3 Biological attribute : Dehydrogenase enzyme activity

Table 3.2. Standard methods adopted for analysis of physical attributes of soil

Parameters	Method	Reference
Bulk density	Core sampling	Blake and Hartge, 1986
Particle density	Pycnometer	Blake and Hartge, 1986
Maximum water holding capacity	Keen-Raczkowski box (Gravimetric method)	Keen and Raczkowski, 1921
Porosity	Using values of bulk density and particle density	Hao *et al.*, 2019
Soil moisture content	Gravimetric method	Blake and Hartge, 1986

Table 3.3. Standard methods adopted for analysis of chemical attributes of soil

Parameter	Method	Reference
pH	1:2.5 (w/v) soil-water suspension, measured in pH meter	Jackson , 1973
Electrical conductivity	Supernatant solution of 1:2.5 (w/v) soil-water suspension , measured in conductivity meter	Jackson , 1973
Organic carbon	Wet-oxidation method	Walkley and Black, 1934
Exchangeable acidity	Extraction with KCl and titration against NaOH	Gillman, 1979
Available nitrogen	Alkaline permanganate method	Subbiah and Asija, 1956

Available phosphorus	Extraction with Bray no.1 reagent and estimation with spectrophotometer at 660 nm	Bray and Kurtz, 1945
Available potassium	Extraction with neutral normal ammonium acetate solution and analysis by flame photometry	Jackson, 1958
Available calcium and magnesium	Extraction with neutral normal ammonium acetate solution followed by atomic absorption spectrometry	Jackson ,1958
Available sulphur	Extraction with 0.15% $CaCl_2$ followed by spectrometry	Williams and Steinberg, 1969
Available zinc, iron, manganese and copper	Extraction with 0.1 M HCl followed by estimation in ICP OES	Lindsay and Norvell, 1978
Available boron	Extraction using hot water followed by estimation with spectrophotometer	Jackson, 1958

Table 3.4 Standard methods adopted for analysis of biological attributes

Parameter	**Method**	**Reference**
Dehydrogenase enzyme activity	Incubation with TTC and estimation of TPF with spectrophotometer at 485 nm	Lenhard, 1956

3.2.2 Statistical analysis of computed data

The generated data of soil variables was tested for their statistical significance including correlation analysis using SPSS version 16.0 software (SPSS, Inc., 2007)

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

The key soil quality parameters were identified, analysed and aggregated by Principal Component Analysis (PCA) and the best indicators for evaluating soil quality were selected using SPSS version 16.0 (SPSS Inc., 2007) and a Minimum Data Set (MDS) was prepared.

3.2.4 Formulation of SQI

After setting up of minimum data set (MDS), the values of indicators were transformed into dimensionless scores . Non linear scoring method was used for scoring and these scores were multiplied with respective weightage factor determined by the concerned PC (Principal component) groups. Weightage factor is the ratio of variance to total variance. Using weighted additive method, the products of score and weightage factor were summed up to generate Soil Quality Index (SQI).

3.2.5 Generation of maps using GIS

The results obtained from analyses of different soil parameter were added as attributes to the GIS layers created. Geographic Information System (GIS) based thematic maps were prepared for the soil parameters using ArcGIS 10.5.1 software. Spatial variability of different parameters of soil in the AEU were assessed. The spatial distribution of SQI generated as GIS maps in the post flood soils of AEU 15 will be useful for planners and policy makers in the management and monitoring of the degraded areas for improving soil quality.

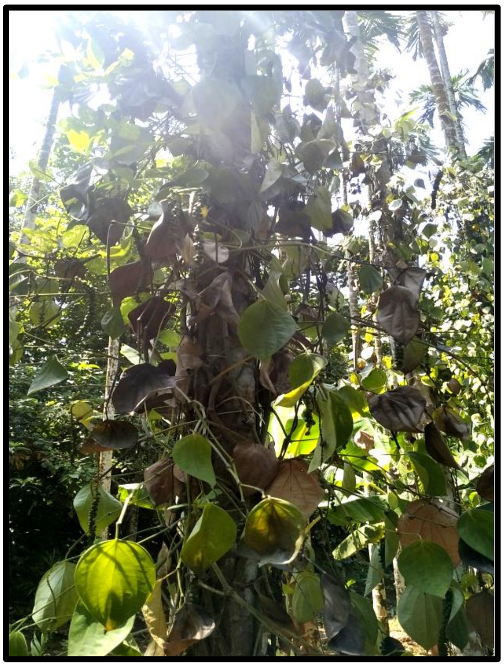
Plate 1. Collection of information on flood affected areas from Krishibhavan at Puthur panchayat

Plate 2. Interaction with the farmer in Varantharappilly panchayat

Plate 3. Soil sample collection in Pananchery panchayat

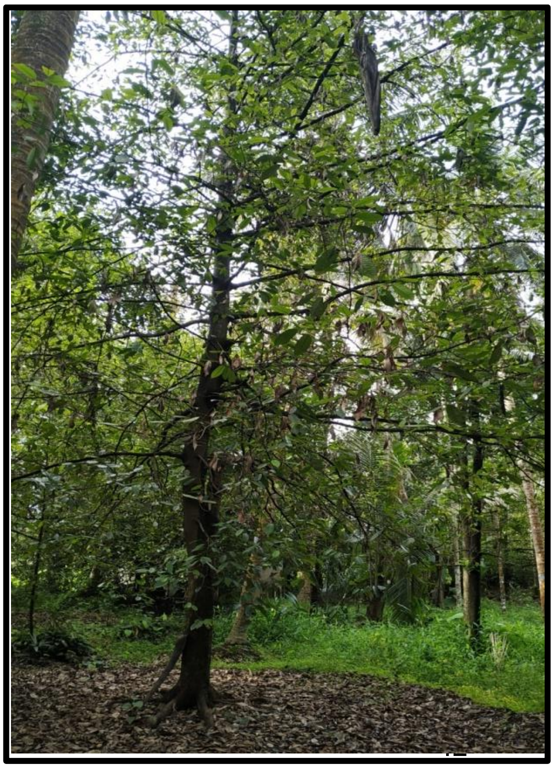
Plate 4. Views of farmers' fields from flood affected locations in AEU 15 of Thrissur

a. Wilting of pepper observed in Pazhayannur panchayat after floods



b. Crop loss observed in banana in Mattathur panchayat

c. Wilting of leaves in nutmeg observed in Pananchery panchayat after floods



RESULTS

4. RESULTS

A comprehensive survey was conducted in AEU 15 of Thrissur district to collect information of the flood affected area. Since Panchayats form the functional units of an agroecological unit, the five panchayats in AEU 15 of Thrissur district were analysed and compared. Most of the farmers in the AEU possessed landholding size less than 1 ha. The study area was subjected to stagnation (2ft to 1m) of flood water for a period of two to three days. The predominant crops and cropping systems of the AEU were identified (Table 4.1). Geo-referenced soil samples were collected and the laboratory analysis of the samples yielded the following results:

4.1 Physical attributes of post flood soils of AEU 15

Physical parameters of soil samples collected from flood affected areas were studied for bulk density, particle density, porosity, moisture content and maximum water holding capacity.

4.1.1 Bulk density

The bulk density values of AEU 15 ranged from 0.83 in Varantharappilly (Table 4.5) to 1.74 Mg m^{-3} in Mattathur (Table 4.6) with a mean value of 1.33 Mg m^{-3} (Appendix I). The highest mean value of bulk density among the panchayats was observed in Puthur panchayat (1.37 Mg m^{-3}) and the lowest in Pazhayannur panchayat (1.30 Mg m^{-3}) (Table 4.7). There was no significant difference in bulk density between different panchayats (Table 4.7).

4.1.2 Particle density

The particle density in the AEU 15 varied from 2.04 Mg m^{-3} in Pananchery (Table 4.3) to 2.99 Mg m^{-3} in Puthur (Table 4.5) and Mattathur (Table 4.6) with a mean of 2.50 Mg m^{-3} (Appendix I). The highest mean particle density was reported in Pazhayannur panchayat (2.60 Mg m^{-3}) and the lowest in Pananchery panchayat (2.39 Mg m^{-3}) (Table 4.8). Statistical analysis revealed that the particle density values of Mattathur, Puthur and Pazhayannur panchayats were on par and they differed significantly with Pananchery panchayat (Table 4.8).

4.1.3 Porosity

The porosity of the AEU ranged from 25.90% in Pananchery (Table 4.3) to 63.37 % in Pazhayannur panchayat (Table 4.2) with an average value of 46.19%. The highest mean porosity was obtained from Pazhayannur panchayat (49.62%) and the lowest from Pananchery panchayat (44.96%) (Table 4.9). Statistical analysis revealed that there was no significant difference in porosity between the panchayats.

4.1.4 Maximum water holding capacity

Maximum water holding capacity values of AEU 15 ranged from 29.28% in Puthur (Table 4.4) to 57.88% in Varantharappilly (Table 4.5) with a mean value of 43.89% (Appendix I) . The panchayats differed significantly in MWHC (Table 4.10). Mattathur and Pazhayannur panchayats were on par. The highest mean MWHC was observed in Varantharappilly panchayat (48.26%) and the lowest from Puthur panchayat (29.28%) (Table 4.10) .

4.1.5 Moisture content

The soil moisture content of soils in the AEU ranged from 6.19% in Mattathur (Table 4.6) to 59.44% in Varantharappilly (Table 4.5). The mean moisture content was highest in Pananchery panchayat (27.82%)(Table 4.11) and lowest in Mattathur panchayat (19.95%) (Table 4.11). The panchayats differed significantly in terms of moisture content in their soils. Mattathur and Puthur panchayats were on par in terms of moisture content (Table 4.11). Varantharappilly and Pazhayannur panchayats were on par and Puthur and Mattathur panchayats were on par.

Table 4.1 Crop details of different panchayats in AEU 15 of Thrissur district

Panchayat	Area	Crops cultivated
Pazhayannur	59.03 km^2	Coleus, coconut, arecanut, arrowroot, bottlegourd, cowpea, turmeric, banana, *Coccinia sp*., pepper
Pananchery	141.71 km^2	Nutmeg, coconut, banana, arecanut, rubber, fodder grass, bittergourd, cowpea, ashgourd, pepper
Puthur	79.07 km^2	Nutmeg, coconut, banana, arecanut, pepper
Varantharappilly	102.82 km^2	Rubber, nutmeg, coconut,banana, arecanut, cowpea
Mattathur	103.11 km^2	Banana, elephant foot yam, arecanut, coconut, nutmeg, turmeric, pepper, cassava

Table 4.2 Physical properties of soils of Pazhayannur panchayat in AEU 15 of Thrissur district

Sample no.	Bulk density (Mg m^{-3})	Moisture content (%)	Particle density (Mg m^{-3})	Porosity (%)	Maximum water holding capacity (%)
1	1.39	11.64	2.66	47.74	49.17
2	1.21	12.83	2.72	55.30	44.09
3	1.25	25.27	2.50	50.13	41.60
4	1.63	13.97	2.54	35.66	39.51
5	1.25	10.26	2.44	48.67	43.30
6	1.20	16.35	2.87	58.35	39.61
7	1.10	32.92	2.58	57.15	36.52
8	1.44	23.30	2.45	41.33	38.42
9	1.56	18.77	2.96	47.14	40.45
10	1.10	25.31	2.23	50.88	55.48
11	1.34	26.42	2.42	44.34	43.13
12	1.27	33.74	2.27	44.31	41.23
13	1.36	18.41	2.79	51.17	44.46
14	1.42	28.34	2.78	48.79	52.18
15	1.00	43.21	2.72	63.37	44.70

Table 4.3 Physical properties of soils of Pananchery panchayat in AEU 15 of Thrissur district

Sample no.	Bulk density (Mg m^{-3})	Moisture content (%)	Particle density (Mg/m^{-3})	Porosity (%)	Maximum water holding capacity (%)
1	1.44	21.40	2.36	39.13	37.57
2	1.50	23.91	2.43	38.20	32.42
3	1.43	32.00	2.38	40.01	40.08
4	1.16	42.97	2.30	49.74	46.07
5	1.23	32.74	2.22	44.57	45.74
6	1.22	38.02	2.05	40.47	39.32
7	1.60	22.84	2.53	36.81	30.45
8	1.12	28.65	2.40	53.22	49.21
9	1.31	34.52	2.04	35.86	47.09
10	1.47	25.73	2.43	39.28	40.10
11	1.21	35.20	2.55	52.72	42.16
12	1.48	21.30	2.37	37.59	40.99
13	1.11	23.17	2.48	55.34	40.32
14	1.36	19.70	2.42	43.67	31.83
15	1.15	41.94	2.65	56.44	44.89
16	1.06	28.82	2.43	56.45	40.01
17	1.24	21.31	2.29	45.95	43.98
18	1.26	30.64	2.20	42.81	44.64
19	1.32	31.34	2.27	41.83	42.67
20	1.32	17.33	2.48	46.70	37.98
21	1.10	36.70	2.63	58.29	45.39
22	1.58	21.78	2.56	38.26	38.78
23	1.37	28.49	2.84	51.60	49.72
24	1.52	25.18	2.56	40.81	35.72
25	1.51	22.35	2.53	40.39	50.91
26	0.90	22.63	2.12	57.61	37.03
27	1.65	19.55	2.22	25.90	34.52
28	1.08	31.73	2.24	51.63	36.02
29	1.35	25.54	2.29	41.18	42.64
30	1.32	27.02	2.45	46.20	48.05

Table 4.4 Physical properties of soils of Puthur panchayat in AEU 15 of Thrissur district

Sample no..	Bulk density (Mg m^{-3})	Moisture content (%)	Particle density (Mg m^{-3})	Porosity (%)	Maximum water holding capacity (%)
1	1.32	19.19	2.51	47.62	54.42
2	1.46	20.59	2.82	48.45	50.86
3	1.35	23.34	2.21	39.20	48.60
4	1.35	29.85	2.26	40.50	47.79
5	1.22	17.22	2.51	51.28	46.30
6	1.49	21.48	2.54	41.31	44.54
7	1.37	16.42	2.65	48.09	45.09
8	1.50	18.37	2.58	41.76	44.43
9	1.45	18.40	2.99	51.67	29.28
10	1.37	16.42	2.26	39.30	49.33
11	1.17	37.70	2.25	47.89	45.82
12	1.32	15.20	2.70	51.07	43.35
13	1.33	31.89	2.70	50.82	38.27
14	1.54	12.26	2.92	47.45	44.71
15	1.38	7.86	2.62	47.19	44.22
16	1.36	20.81	2.47	44.85	53.76

Table 4.5 Physical properties of soils of Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	Bulk density (Mg m^{-3})	Moisture content (%)	Particle density (Mg m^{-3})	Porosity (%)	Maximum water holding capacity (%)
1	1.19	23.23	2.63	54.82	46.67
2	1.27	17.18	2.58	61.79	49.72
3	1.34	33.24	2.19	56.52	55.06
4	1.32	15.65	2.39	54.82	42.98
5	1.37	25.19	2.45	52.18	49.57
6	1.44	29.53	2.40	50.56	50.55
7	1.07	15.43	2.81	49.15	44.57
8	1.31	30.96	2.33	47.36	52.19
9	1.54	21.08	2.48	46.37	45.06
10	1.35	27.57	2.16	45.37	44.50
11	1.58	16.16	2.54	44.71	52.90
12	1.58	20.47	2.50	44.27	41.50
13	1.52	23.08	2.48	43.52	51.46
14	1.47	27.52	2.89	42.82	43.35
15	1.18	32.00	2.46	40.10	52.91
16	1.32	17.39	2.30	39.86	51.13
17	1.03	59.44	2.36	39.02	57.88
18	1.52	20.18	2.84	38.40	37.30
19	1.39	25.81	2.30	37.91	48.70
20	1.30	25.07	2.38	37.63	49.93
21	1.43	22.14	2.72	37.22	50.99
22	0.83	29.43	2.51	36.96	42.74

Table 4.6 Physical properties of soils of Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	Bulk density (Mg m^{-3})	Moisture content (%)	Particle density (Mg m^{-3})	Porosity (%)	Maximum water holding capacity (%)
1	1.34	26.87	2.21	39.51	50.58
2	1.38	24.97	2.42	42.76	49.95
3	1.39	20.84	2.70	48.61	33.47
4	1.56	20.54	2.38	34.59	36.74
5	1.36	28.58	2.92	53.63	47.16
6	1.20	24.60	2.49	51.92	49.38
7	1.17	18.32	2.84	58.97	49.59
8	1.74	10.58	2.67	34.82	42.28
9	1.53	18.04	2.60	41.28	44.04
10	1.43	18.62	2.37	39.61	40.71
11	1.41	18.50	2.58	45.26	36.02
12	1.41	6.19	2.44	42.02	36.29
13	1.09	13.25	2.62	58.28	32.61
14	1.35	27.40	2.45	44.97	40.15
15	1.28	27.57	2.60	50.71	41.02
16	1.37	22.15	2.43	43.73	47.08
17	1.13	17.20	2.55	55.73	32.05
18	1.56	17.19	2.26	30.96	37.54
19	1.22	25.77	2.99	59.29	42.97
20	1.23	12.07	2.79	55.92	46.39
21	1.33	19.69	2.59	48.79	46.54

Table 4.7 Mean, range and standard deviation of bulk density ($Mg\ m^{-3}$) of soils in AEU 15 of Thrissur district

Panchayat	Bulk density	
	Range	Mean ± SD
Pazhayannur	1.00 - 1.63	1.30^{a} ±0.17
Pananchery	0.90- 1.65	1.31^{a} ±0.18
Puthur	1.17 - 1.54	1.37^{a} ±0.10
Varantharappilly	0.83 – 1.58	1.33^{a} ±0.19
Mattathur	1.09 – 1.74	1.36^{a} ±0.16

Table 4.8 Mean, range and standard deviation of particle density ($Mg\ m^{-3}$) of soils in AEU 15 of Thrissur district

Panchayat	Particle density	
	Range	Mean ± SD
Pazhayannur	2.23- 2.96	2.60^{a} ± 0.21
Pananchery	2.04- 2.84	2.39^{b} ±0.18
Puthur	2.21- 2.99	2.56^{a} ±0.24
Varantharappilly	2.16- 2.89	2.49^{ab} ±0.20
Mattathur	2.21- 2.99	2.57^{a} ±0.21
CD(0.05) = 0.147		

Means followed by different letters in the same column are significantly different at P= 0.05 and means followed by same letters are non-significant.

Table 4.9 Mean, range and standard deviation of porosity (%) of soils in AEU 15 of Thrissur district

Panchayat	Porosity	
	Range	Mean ± SD
Pazhayannur	35.66 - 63.37	49.62[a] ±7.02
Pananchery	25.90 – 58.29	44.96[a] ± 7.86
Puthur	39.20 - 51.67	46.15[a]± 4.41
Varantharappilly	36.96 - 61.79	45.06[a]±7.16
Mattathur	30.96 - 59.29	46.73[a] ± 8.45

Table 4.10 Mean, range and standard deviation of maximum water holding capacity (on gravimetric basis) (%) in AEU 15 of Thrissur district

Panchayat	Maximum water holding capacity	
	Range	Mean ± SD
Pazhayannur	36.52- 55.48	43.59[bc] ±5.19
Pananchery	30.45- 50.91	41.21[c] ± 5.41
Puthur	29.28 – 54.42	45.67[ab] ± 5.95
Varantharappilly	37.30- 57.88	48.26[a] ±5.00
Mattathur	32.05 – 50.58	42.03[bc] ± 6.03
CD(0.05) = 3.995		

Means followed by different letters in the same column are significantly different at P= 0.05 and means followed by same letters are non-significant.

Table 4.11 Mean, range and standard deviation of moisture content (%) of soils in AEU 15 of Thrissur district (on gravimetric basis)

Panchayat	Moisture content(%)	
	Range	Mean ± SD
Pazhayannur	10.26 – 43.21	$22.72^{ab} \pm 9.38$
Pananchery	17.33 – 42.97	$27.82^{a} \pm 6.78$
Puthur	7.86 – 37.70	$20.44^{b} \pm 7.45$
Varantharappilly	15.43 – 59.44	$25.35^{ab} \pm 9.36$
Mattathur	6.19 – 28.58	$19.95^{b} \pm 6.05$
CD(0.05) = 5.625		

Means followed by different letters in the same column are significantly different at P= 0.05.

4.2 Chemical attributes of post flood soils of AEU 15

4.2.1 Soil reaction

Soil reaction was expressed as measured values of pH in soils. The soils collected from all the panchayats were acidic in nature. The pH values ranged from 4.48 in Pananchery (Table 4.13) to 6.75 in Mattathur (Table 4.16) with a mean value of 5.67 (Appendix I). The highest mean pH was found in Mattathur panchayat (6.19) and the lowest mean pH in Pananchery (5.34) (Table 4.17). Statistically, there was significant difference between the panchayats. Pananchery and Varantharappilly panchayats measured the lowest pH and were on par (Table 4.17).

4.2.2 Exchangeable acidity

Exchangeable acidity values of the AEU ranged from 0.80 in Pananchery (Table 4.13) and Varantharappilly (Table 4.15) to 2.50 cmol(+)kg^{-1} (All the five panchayats) with a mean value of 1.80 cmol(+) kg^{-1} (Appendix I). The highest mean value was observed in Pananchery panchayat (1.94 cmol(+) kg^{-1}) and lowest in Pazhayannur panchayat (1.67 cmol(+) kg^{-1}) and there was no significant difference in exchangeable acidity between different panchayats (Table 4.18).

4.2.3 Electrical conductivity

The soluble salt content as expressed by electrical conductivity in the AEU ranged from 0.020 in Pananchery (Table 4.13) to 0.148 dS m^{-1} in Mattathur panchayat (Table 4.16) with a mean value of 0.051 dS m^{-1} (Appendix I). The soluble salt content in soils of all panchayats has shown an EC value of less than 1 dS m^{-1}. As per statistical study, there was significant difference in EC between different panchayats . Pazhayannur, Mattathur and Puthur panchayats were on par (Table 4.19). The highest mean value was observed in Pazhayannur (0.066 dS m^{-1}) and the lowest in Pananchery (0.031 dS m^{-1}) (Table 4.19).

4.2.4 Organic carbon

The organic carbon content in post flood soils of AEU 15 ranged from 0.19 % in Pananchery (Table 4.13) to 2.24% in Pananchery (Table 4.13) with an average of

0.94% (Appendix I). There was significant difference between different panchayats in case of organic carbon content in their soils (Table 4.20). The highest mean value was obtained from Varantharappilly panchayat (1.19%) and lowest from Puthur panchayat (0.77%) (Table 4.20). Pananchery, Puthur and Mattathur panchayats were on par.Spatial distribution of organic carbon in AEU 15 of Thrissur district of Kerala is given in Fig 4.1.

Table 4.12 Chemical properties of soils of Pazhayannur panchayat in AEU 15 of Thrissur district

Sample no.	pH	Exchangeable acidity (cmol kg^{-1})	Electrical conductivity (dS m^{-1})	Organic carbon (%)
1	6.28	0.83	0.070	1.06
2	5.12	2.50	0.084	0.78
3	6.28	1.67	0.048	1.08
4	5.66	0.83	0.093	0.70
5	5.90	1.67	0.038	0.90
6	6.51	0.83	0.052	1.25
7	5.86	1.67	0.064	0.25
8	6.52	1.67	0.069	0.79
9	6.12	2.50	0.080	0.59
10	4.50	2.50	0.055	0.97
11	6.61	0.83	0.042	0.92
12	5.49	2.50	0.061	1.76
13	5.78	1.67	0.078	1.14
14	5.51	0.83	0.076	1.49
15	5.18	2.50	0.075	0.78

Table 4.13 Chemical properties of soils of Pananchery panchayat in AEU 15 of Thrissur district

Sample no.	pH	Exchangeable acidity (cmol kg^{-1})	Electrical conductivity (dS m^{-1})	Organic carbon (%)
1	5.89	1.67	0.029	0.69
2	5.71	1.67	0.024	0.32
3	5.44	1.67	0.031	0.60
4	6.01	0.83	0.031	0.75
5	5.86	2.50	0.043	0.45
6	4.98	1.67	0.032	1.49
7	5.08	2.50	0.027	0.45
8	5.63	2.50	0.020	0.78
9	5.38	2.50	0.033	2.24
10	5.28	1.67	0.022	0.89
11	5.37	1.67	0.030	1.50
12	5.52	1.67	0.023	0.86
13	4.83	2.50	0.023	0.96
14	5.56	1.67	0.022	0.78
15	5.51	2.50	0.031	1.83
16	5.71	2.50	0.026	0.77
17	5.17	1.67	0.034	1.08
18	5.72	2.50	0.025	1.40
19	5.81	1.67	0.031	1.37
20	5.93	1.67	0.044	0.63
21	4.82	1.67	0.023	0.63
22	5.37	1.67	0.033	0.44
23	4.82	2.50	0.022	0.38
24	4.80	2.50	0.038	0.56
25	5.41	1.67	0.060	1.02
26	5.71	1.67	0.037	0.63
27	4.63	0.80	0.025	0.65
28	4.86	2.50	0.044	0.63
29	4.83	2.50	0.022	0.19
30	4.48	1.67	0.047	0.84

Table 4.14 Chemical properties of soils of Puthur panchayat in AEU 15 of Thrissur district

Sample no.	pH	Exchangeable acidity (cmol kg^{-1})	Electrical conductivity (dS m^{-1})	Organic carbon (%)
1	4.88	2.50	0.068	0.43
2	5.91	1.67	0.054	0.80
3	5.63	2.50	0.037	0.66
4	6.65	0.83	0.074	0.92
5	5.61	0.83	0.062	1.21
6	6.71	1.67	0.134	0.55
7	6.46	1.67	0.037	1.13
8	6.64	2.50	0.089	0.73
9	5.71	1.67	0.053	0.55
10	5.29	1.67	0.046	0.61
11	5.39	1.67	0.060	1.04
12	6.42	1.67	0.025	0.69
13	5.53	2.50	0.100	0.60
14	5.39	1.67	0.046	1.35
15	5.87	1.67	0.044	0.54
16	5.48	2.50	0.039	0.57

Table 4.15 Chemical properties of soils of Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	pH	Exchangeable acidity (cmol kg^{-1})	Electrical conductivity (dS m^{-1})	Organic carbon (%)
1	4.69	2.50	0.042	1.03
2	4.89	0.80	0.051	0.98
3	5.08	0.80	0.036	1.61
4	4.91	2.50	0.037	1.33
5	5.08	2.50	0.037	1.14
6	5.63	0.83	0.051	0.46
7	5.64	1.67	0.032	1.22
8	5.50	1.67	0.067	2.04
9	4.76	1.67	0.050	1.37
10	5.25	2.50	0.050	1.50
11	5.51	0.80	0.043	1.45
12	5.27	1.67	0.032	0.62
13	5.33	2.50	0.041	1.51
14	5.94	1.67	0.050	0.47
15	5.35	1.67	0.050	1.27
16	5.53	1.67	0.036	1.27
17	5.05	1.67	0.033	1.49
18	5.93	1.67	0.059	1.52
19	5.61	2.50	0.067	0.95
20	5.93	2.50	0.059	1.34
21	5.68	1.67	0.052	0.66
22	5.68	1.67	0.069	1.01

Table 4.16 Chemical properties of soils of Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	pH	Exchangeable acidity (cmol kg^{-1})	Electrical conductivity (dS m^{-1})	Organic carbon (%)
1	6.72	0.83	0.148	0.46
2	5.37	2.50	0.051	0.68
3	6.35	1.67	0.058	0.90
4	6.75	1.67	0.060	1.26
5	6.41	0.83	0.102	1.06
6	6.10	2.50	0.046	0.75
7	5.17	2.50	0.060	1.06
8	6.50	0.83	0.100	0.55
9	5.82	1.67	0.033	0.70
10	6.29	2.50	0.110	1.29
11	5.54	0.83	0.046	0.96
12	6.43	1.67	0.047	0.68
13	6.31	1.67	0.040	0.67
14	6.56	1.67	0.053	1.32
15	6.23	2.50	0.029	0.98
16	6.64	0.83	0.118	1.47
17	6.74	1.67	0.068	1.15
18	6.12	0.83	0.044	0.88
19	6.22	1.67	0.038	0.28
20	5.34	2.50	0.059	1.01
21	6.32	2.50	0.039	0.58

Table 4. 17 Mean, range and standard deviation of pH of soils in AEU 15 of Thrissur district

Panchayat	pH	
	Range	Mean ± SD
Pazhayannur	4.50 -6.61	5.82^{b} ±0.6
Pananchery	4.48 -6.01	5.34^{c} ± 0.43
Puthur	4.88 -6.71	5.85^{ab} ± 0.56
Varantharappilly	4.69 -5.94	5.37^{c} ±0.38
Mattathur	5.17 -6.75	6.19^{a} ± 0.48
CD (0.05) = 0.346		

Table 4. 18 Mean, range and standard deviation of exchangeable acidity (cmol (+) kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Exchangeable acidity	
	Range	Mean ± SD
Pazhayannur	0.83- 2.50	1.67^{a} ±0.70
Pananchery	0.80-2.50	1.94^{a}± 0.51
Puthur	0.83- 2.50	1.82^{a}± 0.55
Varantharappilly	0.80 – 2.50	1.78^{a}±0.60
Mattathur	0.83-2.50	1.71^{a}± 0.67

Means followed by different letters in the same column are significantly different at P= 0.05 and means followed by same letters are non-significant.

Table 4. 19 Mean, range and standard deviation of electrical conductivity (dS m^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Electrical conductivity	
	Range	Mean ± SD
Pazhayannur	0.038-0.093	0.066^{a} ±0.02
Pananchery	0.020-0.060	0.031^{c} ± 0.01
Puthur	0.025-0.134	0.061^{ab} ± 0.03
Varantharappilly	0.032-0.069	0.047^{b} ±0.01
Mattathur	0.029- 0.148	0.064^{a} ± 0.03
CD (0.05) = 0.015		

Table 4. 20 Mean, range and standard deviation of organic carbon content (%) in AEU 15 of Thrissur district

Panchayat	Organic carbon content	
	Range	Mean ± SD
Pazhayannur	0.25- 1.76	0.97^{ab} ±0.37
Pananchery	0.19-2.24	0.86^{b} ± 0.46
Puthur	0.43-1.35	0.77^{b} ± 0.27
Varantharappilly	0.46- 2.04	1.19^{a} ±0.39
Mattathur	0.28- 1.47	0.89^{b} ± 0.31
CD(0.05) = 0.277		

Means followed by different letters in the same column are significantly different at P= 0.05.

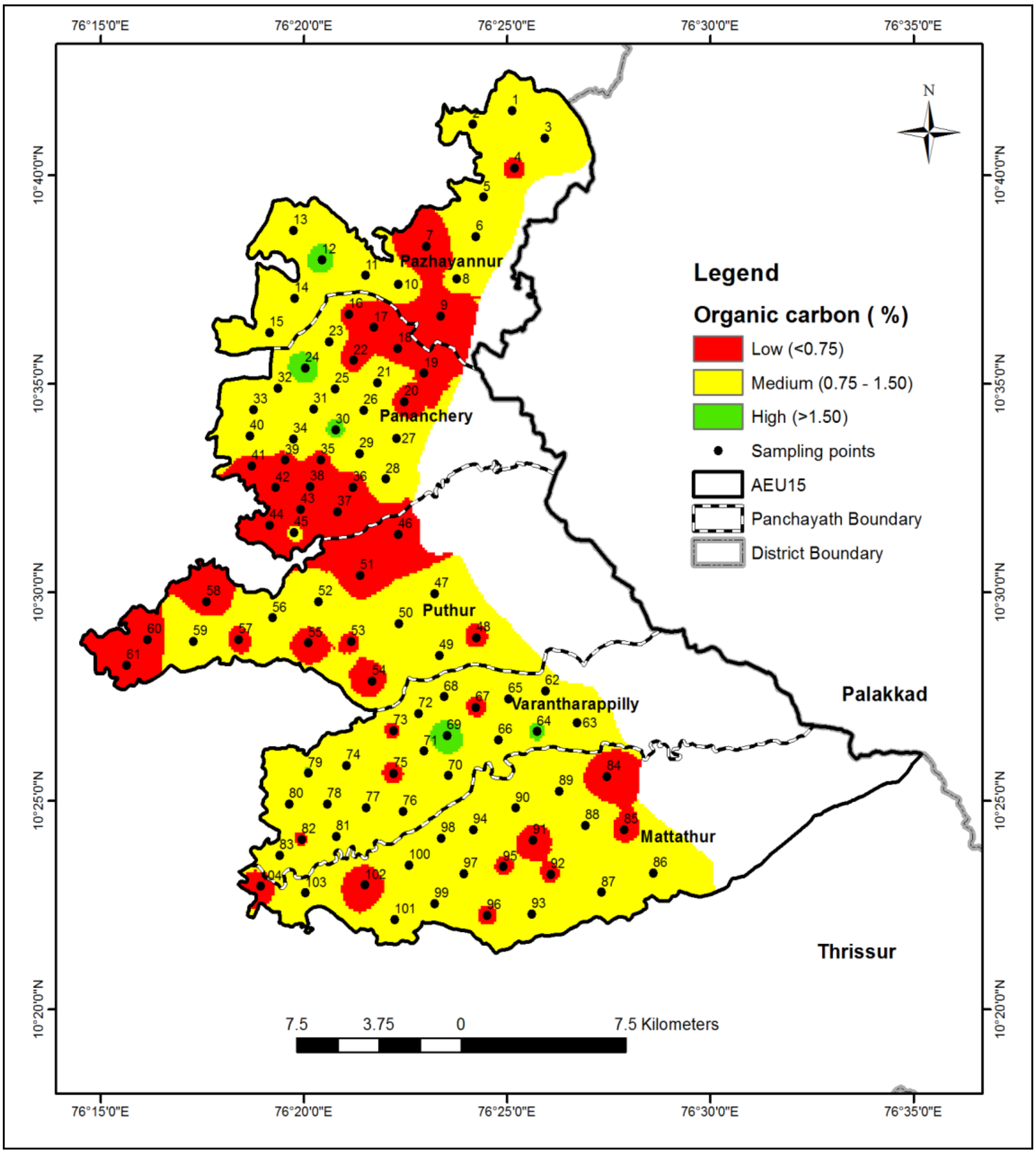


Fig 4.1 Spatial distribution of organic carbon in AEU 15 of Thrissur district of Kerala

4.3 Status of available primary nutrients in post flood soils of AEU 15

4.3.1 Available nitrogen

The available nitrogen ranged from 100.35 in Pananchery (Table 4.22) to 539.39 kg ha^{-1} in Pananchery (Table 4.22) with a mean of 172.36 kg ha^{-1} (Appendix I). The highest mean available nitrogen content was reported in Pananchery panchayat (181.05 kgha^{-1}) and lowest in Puthur panchayat (155.23 kg ha^{-1}) (Table 4.26). Statistical studies revealed that there was no significant difference in available nitrogen contents between the panchayats (Table 4.26). Spatial distribution of available nitrogen in AEU 15 of Thrissur district of Kerala is given Fig 4.2.

4.3.2 Available phosphorus

Available phosphorus content of the AEU ranged from 15.77 in Mattathur (Table 4.25) to 762.54 kg ha^{-1} in Varantharappilly panchayat (Table 4.24)with a mean value of 231.88 kg ha^{-1} (Appendix I) . According to statistical analysis, the panchayats differed significantly in terms of available phosphorus in soils**.** Pazhayannur, Puthur and Mattathur panchayats were on par (Table 4.27). The highest mean available phosphorus was recorded in Varantharappilly panchayat (419.41 kg ha^{-1}) and the lowest mean available phosphorus was recorded in Pananchery panchayat (86.1 kg ha^{-1}) (Table 4.27).

4.3.3 Available potassium

Available potassium content of the AEU ranged from 53.20 in Pananchery (Table 4.22) to 648.59 kg ha^{-1} in Puthur (Table 4.23) with an average value of 241.34 kg ha^{-1} (Appendix I). There was significant difference in available potassium between different panchayats. Pazhayyannur and Pananchery panchayats were on par and Puthur and Varantharappilly panchayats were on par in terms of their available potassium contents (Table 4.28). The highest mean available potassium content was observed in Varantharappilly panchayat (295.83 kg ha^{-1}) and the lowest mean in Pazhayannur panchayat (201.51 kg ha^{-1}) (Table 4.28). Spatial distribution of available potassium in AEU 15 of Thrissur district of Kerala is given in Fig 4.3.

Table 4.21 Primary and secondary nutrient status of Pazhayannur panchayat in AEU 15 of Thrissur district

Sample no.	Available primary nutrients			Available secondary nutrients		
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
1	188.16	294.37	172.59	588.50	135.35	13.58
2	125.44	97.97	150.42	298.10	85.75	11.48
3	275.97	76.73	209.10	691.50	135.25	9.61
4	188.16	398.84	124.43	569.50	180.80	16.44
5	150.53	55.54	171.81	481.95	206.25	9.02
6	175.62	61.39	155.23	683.50	209.10	12.63
7	188.16	60.91	148.51	684.50	215.75	10.06
8	175.62	343.56	170.80	854.50	267.35	15.50
9	150.53	94.14	363.55	455.40	103.00	17.52
10	188.16	73.24	227.25	571.00	166.80	16.75
11	125.44	98.24	145.94	826.00	170.35	9.13
12	175.62	192.79	328.94	913.50	304.65	10.41
13	125.44	379.76	219.86	743.50	140.70	17.40
14	200.70	428.47	91.84	1178.50	312.35	10.95
15	150.53	574.60	342.38	413.00	129.60	12.98

Table 4.22 Primary and secondary nutrient status of Pananchery panchayat in AEU 15 of Thrissur district

Sample no.	Available primary nutrients			Available secondary nutrients		
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
1	150.53	182.60	219.14	1179.50	228.35	2.07
2	125.44	43.30	255.92	1061.00	97.45	1.68
3	175.62	83.19	170.69	989.00	317.30	4.34
4	188.16	80.60	189.17	1268.50	403.20	3.91
5	213.25	83.38	488.32	1138.00	230.95	1.42
6	125.44	83.38	125.55	620.00	173.15	1.57
7	376.32	38.81	191.97	716.50	93.65	1.96
8	188.16	78.19	129.47	1030.50	202.05	2.50
9	175.62	83.01	193.20	887.50	301.45	2.35
10	163.07	86.07	232.74	900.50	154.65	1.96
11	539.39	78.22	143.47	825.00	154.30	1.60
12	163.07	83.23	360.30	581.00	142.75	4.54
13	163.07	83.23	150.19	315.75	80.70	5.85
14	137.98	83.42	102.59	480.05	127.05	1.53
15	225.79	83.42	205.30	1434.50	339.10	1.99
16	150.53	39.82	237.55	892.00	135.35	2.23
17	188.16	34.26	103.26	557.50	110.15	1.75
18	150.53	82.97	282.35	935.50	209.65	1.69
19	175.62	109.98	343.73	770.50	185.95	2.23
20	150.53	78.15	383.71	711.50	183.85	1.73
21	163.07	83.31	119.73	538.50	93.85	0.40
22	163.07	83.31	112.45	478.65	74.95	0.83
23	100.35	83.48	157.02	819.00	298.30	1.42
24	112.90	80.71	245.06	831.50	164.90	3.04
25	175.62	83.31	122.42	1485.00	253.60	1.25
26	150.53	83.12	88.82	834.50	92.20	2.39
27	213.25	83.12	78.62	407.00	71.65	1.10
28	175.62	83.31	53.20	689.50	102.50	4.78
29	125.44	183.93	223.78	858.00	119.85	2.49
30	125.44	136.17	536.26	411.20	81.05	4.39

Table 4.23 Primary and secondary nutrient status of Puthur panchayat in AEU 15 of Thrissur district

Sample no.	Available primary nutrients			Available secondary nutrients		
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
1	175.62	155.79	648.59	346.95	103.40	5.71
2	150.53	122.72	281.12	665.50	136.95	2.02
3	175.62	232.95	243.38	515.50	125.85	7.15
4	150.53	400.67	315.62	909.00	200.35	13.27
5	188.16	152.90	168.56	568.00	158.90	3.51
6	188.16	223.72	368.59	1091.00	133.60	2.80
7	163.07	224.29	183.46	703.50	129.60	6.67
8	163.07	400.24	307.66	911.50	96.60	8.14
9	150.53	400.39	353.81	607.50	146.05	12.63
10	150.53	336.96	218.40	366.85	85.90	11.73
11	137.98	401.08	328.72	614.50	149.20	15.77
12	150.53	152.16	173.49	360.10	145.10	8.62
13	112.90	357.74	242.93	502.50	174.65	55.09
14	150.53	233.73	211.79	544.50	78.05	8.13
15	125.44	419.99	218.18	434.35	121.70	9.73
16	150.53	124.41	320.10	617.00	158.85	15.14

Table 4.24 Primary and secondary nutrient status of Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	Available primary nutrients			Available secondary nutrients		
	Ni (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
1	163.07	438.08	235.42	394.20	84.65	5.71
2	150.53	458.14	269.47	415.00	89.45	4.86
3	163.07	208.23	316.18	323.55	57.35	2.93
4	163.07	686.41	373.63	712.00	175.90	4.36
5	175.62	643.00	334.88	699.00	155.00	5.64
6	175.62	148.32	411.15	930.50	165.80	7.10
7	150.53	147.38	160.83	610.50	90.50	6.79
8	250.88	218.94	499.07	1121.00	174.20	9.86
9	200.70	694.32	267.12	570.00	63.95	8.23
10	188.16	175.85	273.17	580.50	113.65	9.99
11	225.79	433.43	180.43	660.00	134.85	20.51
12	213.25	565.07	254.69	417.50	100.25	3.42
13	225.79	399.50	231.50	638.50	148.75	6.45
14	188.16	762.54	212.80	572.50	96.50	2.31
15	163.07	171.75	196.78	532.50	132.70	7.15
16	163.07	316.76	435.34	627.00	128.40	4.52
17	112.90	57.30	226.24	644.00	146.65	4.20
18	263.42	609.21	295.12	954.50	128.85	2.76
19	163.07	549.88	367.02	975.00	195.20	5.38
20	163.07	451.75	387.18	659.00	142.15	10.83
21	150.53	615.05	356.50	765.00	124.45	1.98
22	125.44	476.16	223.66	418.90	84.35	3.53

Table 4.25 Primary and secondary nutrient status of Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	Available primary nutrients			Available secondary nutrients		
	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)
1	175.62	623.27	296.02	1636.00	163.00	4.94
2	163.07	329.82	236.10	411.40	55.45	4.54
3	163.07	616.18	245.28	754.50	73.70	4.92
4	150.53	309.95	313.49	701.50	89.85	4.18
5	188.16	492.76	122.86	784.00	67.05	4.67
6	163.07	78.33	333.42	607.50	114.75	4.15
7	200.70	77.96	107.30	496.45	70.10	4.93
8	175.62	15.77	116.59	455.15	30.70	0.99
9	200.70	257.88	146.94	546.50	58.50	4.44
10	100.35	83.57	282.02	1117.50	93.50	5.32
11	175.62	83.01	178.64	763.50	91.70	4.03
12	150.53	291.64	318.42	1486.50	125.90	4.33
13	125.44	80.70	144.48	904.00	113.10	3.90
14	150.53	83.05	272.16	930.50	138.50	4.20
15	150.53	82.85	161.28	509.50	78.55	1.56
16	200.70	237.17	201.04	1891.50	135.65	1.42
17	163.07	78.21	325.47	923.50	118.30	2.10
18	288.51	83.04	226.80	2118.00	137.85	5.39
19	137.98	115.60	206.64	465.40	82.25	4.46
20	137.98	99.94	231.06	432.20	57.75	4.74
21	125.44	614.52	272.50	517.00	69.15	3.91

Table 4. 26 Mean, range and standard deviation of available nitrogen content (kg ha^{-1}) in AEU 15 of Thrissur district

Panchayat	Available nitrogen	
	Range	Mean ± SD
Pazhayannur	125.44- 275.97	172.27^{a}±38.36
Pananchery	100.35 – 539.39	181.05^{a}± 83.58
Puthur	112.90 – 188.16	155.23^{a}± 20.40
Varantharappilly	112.90 – 263.42	179.04^{a}±37.77
Mattathur	100.35 – 288.51	166.06^{a}± 38.44

Table 4.27 Mean, range and standard deviation of available phosphorus content (kg ha^{-1}) in AEU 15 of Thrissur district

Panchayat	Available phosphorus	
	Range	Mean ± SD
Pazhayannur	55.54 – 574.60	215.37^{b} ±171.77
Pananchery	34.26 - 183.93	86.10^{c} ±32.82
Puthur	122.72 - 419.99	271.23^{b} ± 113.53
Varantharappilly	57.30 -762.54	419.41^{a} ±37.77
Mattathur	15.77 - 623.27	225.59^{b} ± 202.05
CD(0.05) = 112.386		

Means followed by different letters in the same column are significantly different at P= 0.05 and means followed by same letters are non-significant.

Table 4. 28 Mean, range and standard deviation of available potassium content (kg ha^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available potassium	
	Range	Mean ± SD
Pazhayannur	91.84 - 363.55	201.51^{b} ±82.24
Pananchery	53.20 – 536.26	208.20^{b} ± 116.92
Puthur	168.56 – 648.59	286.52^{a} ± 116.21
Varantharappilly	160.83 – 499.07	295.83^{a} ±89.70
Mattathur	107.30 – 333.42	222.64^{ab} ± 73.31
CD(0.05) = 71.714		

Means followed by different letters in the same column are significantly different at P= 0.05 .

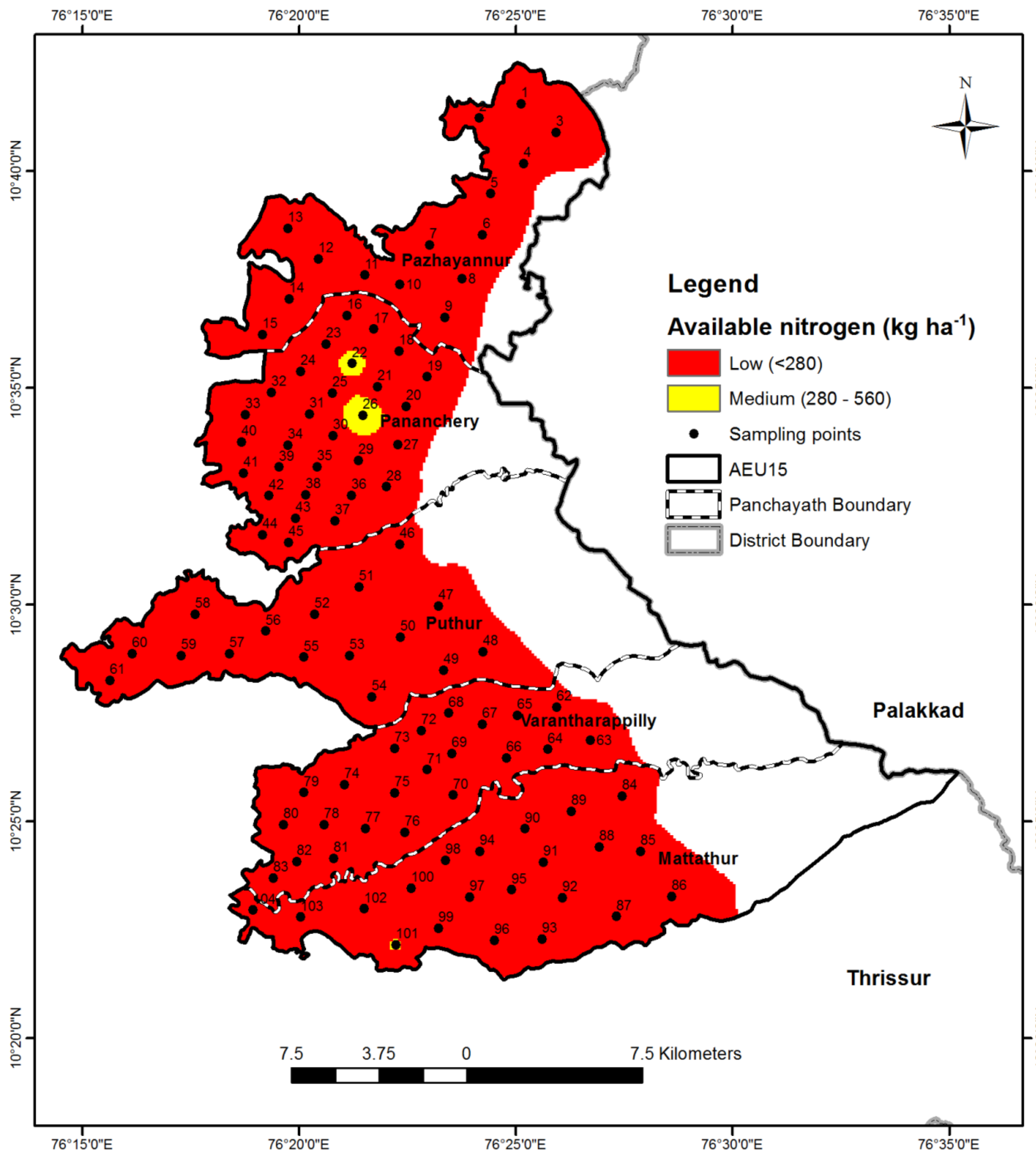


Fig 4.2 Spatial distribution of available nitrogen in AEU 15 of Thrissur district of Kerala

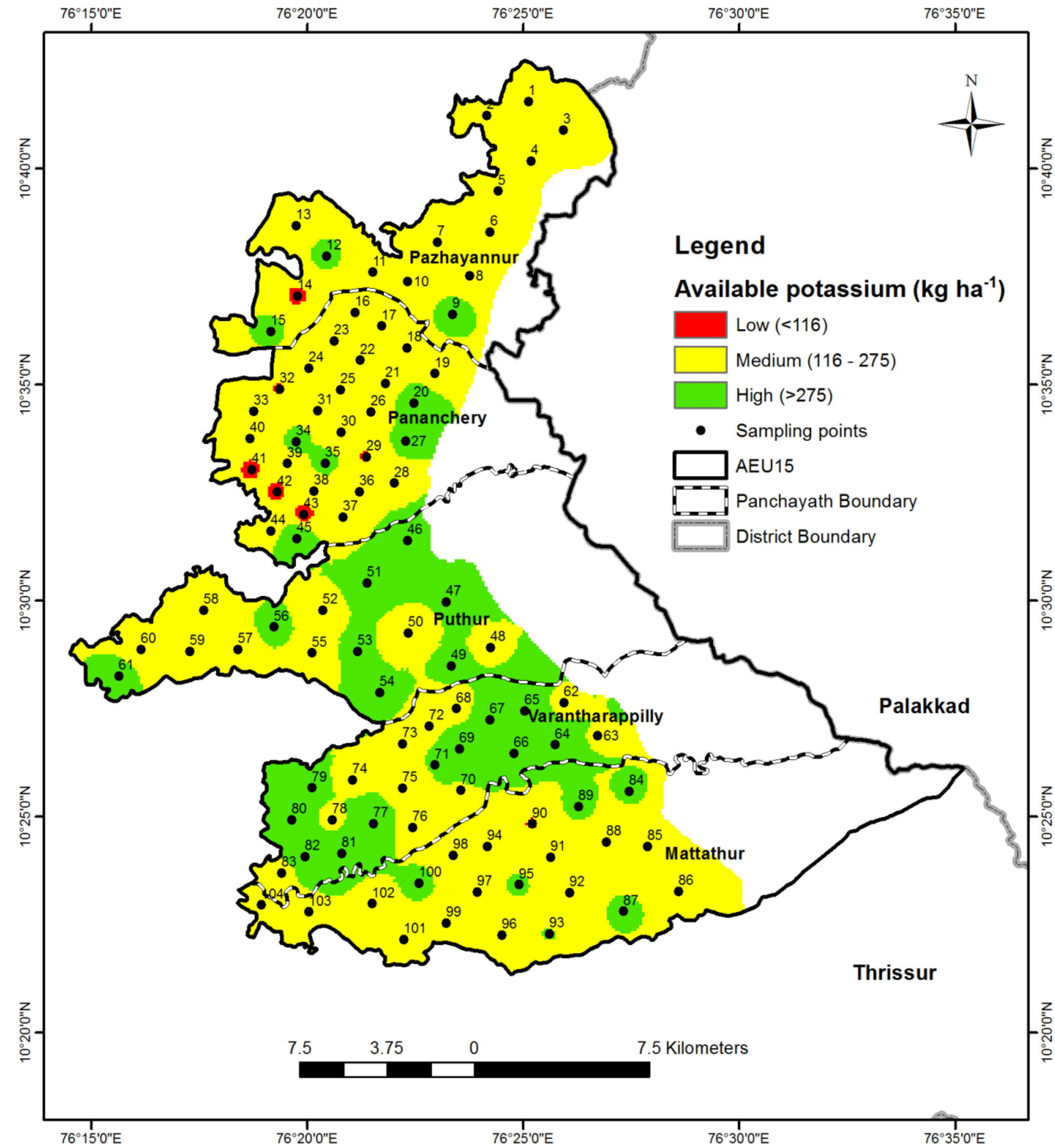


Fig 4.3 Spatial distribution of available potassium in AEU 15 of Thrissur district of Kerala

4.4 Status of available secondary nutrients in post flood soils of AEU 15 of Thrissur district

4.4.1 Available calcium

The available calcium content of the post flood soils ranged from 298.10 in Pazhayannur (Table 4.21) to 2118.00 mg kg^{-1} in Mattathur (Table 4.25) with a mean value of 740.68 mg kg^{-1} (Appendix I). All the panchayats have sufficient calcium content in their soils. Statistically, there was significant difference between panchayats in available calcium content. Pazhayannur and Pananchery panchayats were on par and Puthur and Varantharappilly panchayats were on par (Table 4.29). The highest mean available calcium content was found in Mattathur panchayat (878.67 mg kg^{-1}) and lowest in Puthur panchayat (609.89 mg kg^{-1}) (Table 4.29).

4.4.2 Available magnesium

The available magnesium content in soils ranged from 30.7 in Mattathur (Table 4.25) to 403.2 mg kg^{-1} in Pananchery (Table 4.22) with a mean of 142.6 mg kg^{-1} (Appendix I). More than half (60%) of the soil samples were sufficient in available magnesium content. There was significant difference between different panchayat in case of available magnesium in their soils**.** Varantharappilly and Mattathur panchayats were on par. The highest mean value was observed in Pazhayannur (184.20 mg kg^{-1}) and lowest in Mattathur (93.58 mg kg^{-1}) panchayat (Table 4.30). Spatial distribution of available magnesium in AEU 15 of Thrissur district of Kerala is given in Fig 4.4.

4.4.3 Available sulphur

Available sulphur in soils ranged from 0.40 in Pananchery (Table 4.22) to 55.09 mg kg^{-1} in Puthur (Table 4.23) with an average value of 6.46 mg kg^{-1} (Appendix I) . There was significant difference between different panchayats in available sulphur in their soils (Table 4.31). Pazhayannur and Puthur panchayats were on par and Mattathur and Pananchery panchayats were on par. The highest mean available sulphur was observed in Pazhayannur panchayat (12.90 mg kg^{-1}) and lowest mean in Mattathur panchayat (2.36 mg kg^{-1}) (Table 4.31).Spatial distribution of available sulphur in AEU 15 of Thrissur district of Kerala is given in Fig 4.5**.**

Table 4.29 Mean, range and standard deviation of available calcium content (mg kg^{-1}) in AEU 15 of Thrissur district

Panchayat	Available calcium	
	Range	Mean ± SD
Pazhayannur	298.10 – 1178.50	663.53^{ab} ±222.68
Pananchery	315.75 -1179.50	821.57^{ab} ± 295.07
Puthur	346.95 – 1091.00	609.89^{b} ± 211.62
Varantharappilly	323.55 – 1121.00	646.39^{b} ±205.43
Mattathur	411.40 – 2118.00	878.67^{a} ± 500.05
CD(0.05)= 227.678		

Table 4.30 Mean, range and standard deviation of available magnesium content (mg kg^{-1}) in AEU 15 of Thrissur district

Panchayat	Available magnesium	
	Range	Mean ± SD
Pazhayannur	85.75- 312.35	184.20^{a} ±68.87
Pananchery	71.65 – 403.20	174.13^{ab} ± 88.58
Puthur	78.05 – 200.35	134.05^{bc} ± 32.47
Varantharappilly	57.35 – 195.20	124.25^{c} ±37.54
Mattathur	30.70 – 163.00	93.58^{c} ± 34.35
CD(0.05) = 43.865		

Means followed by different letters in the same column are significantly different at P= 0.05.

Table 4. 31 Mean, range and standard deviation of available sulphur content (mg kg^{-1}) in soils of AEU 15 of Thrissur district

Panchayat	Available sulphur	
	Range	Mean ± SD
Pazhayannur	9.02-17.52	12.90^{a} ±3.12
Pananchery	0.40- 5.85	2.36^{c} ± 1.30
Puthur	2.02 – 55.09	11.63^{a} ± 12.32
Varantharappilly	1.98 – 20.51	6.30^{b} ±4.05
Mattathur	0.99 – 5.39	3.96b^{c} ± 1.29
CD(0.05) = 3.878		

Means followed by different letters in the same column are significantly different at P= 0.05.

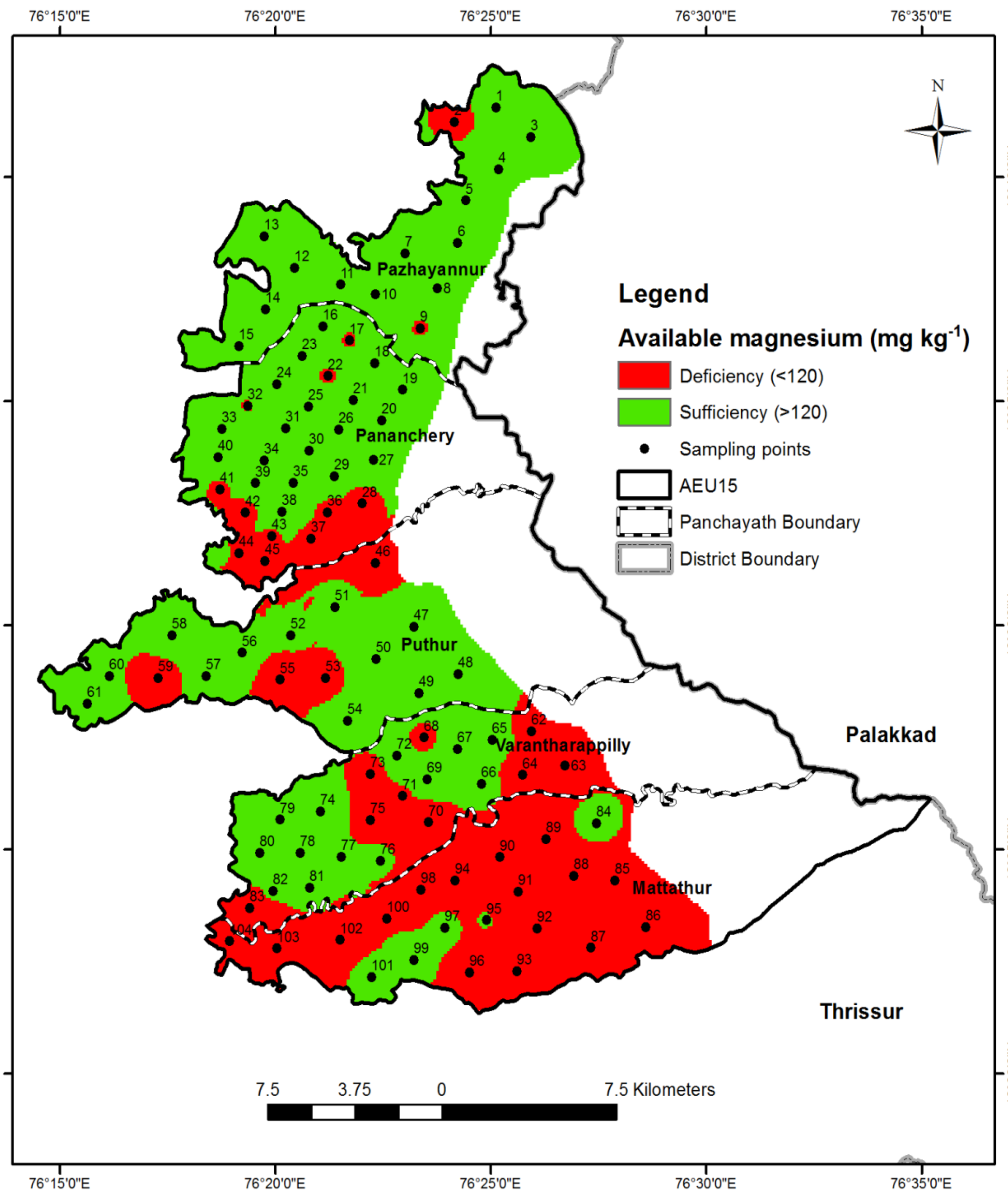


Fig 4.4 Spatial distribution of available magnesium in AEU 15 of Thrissur district of Kerala

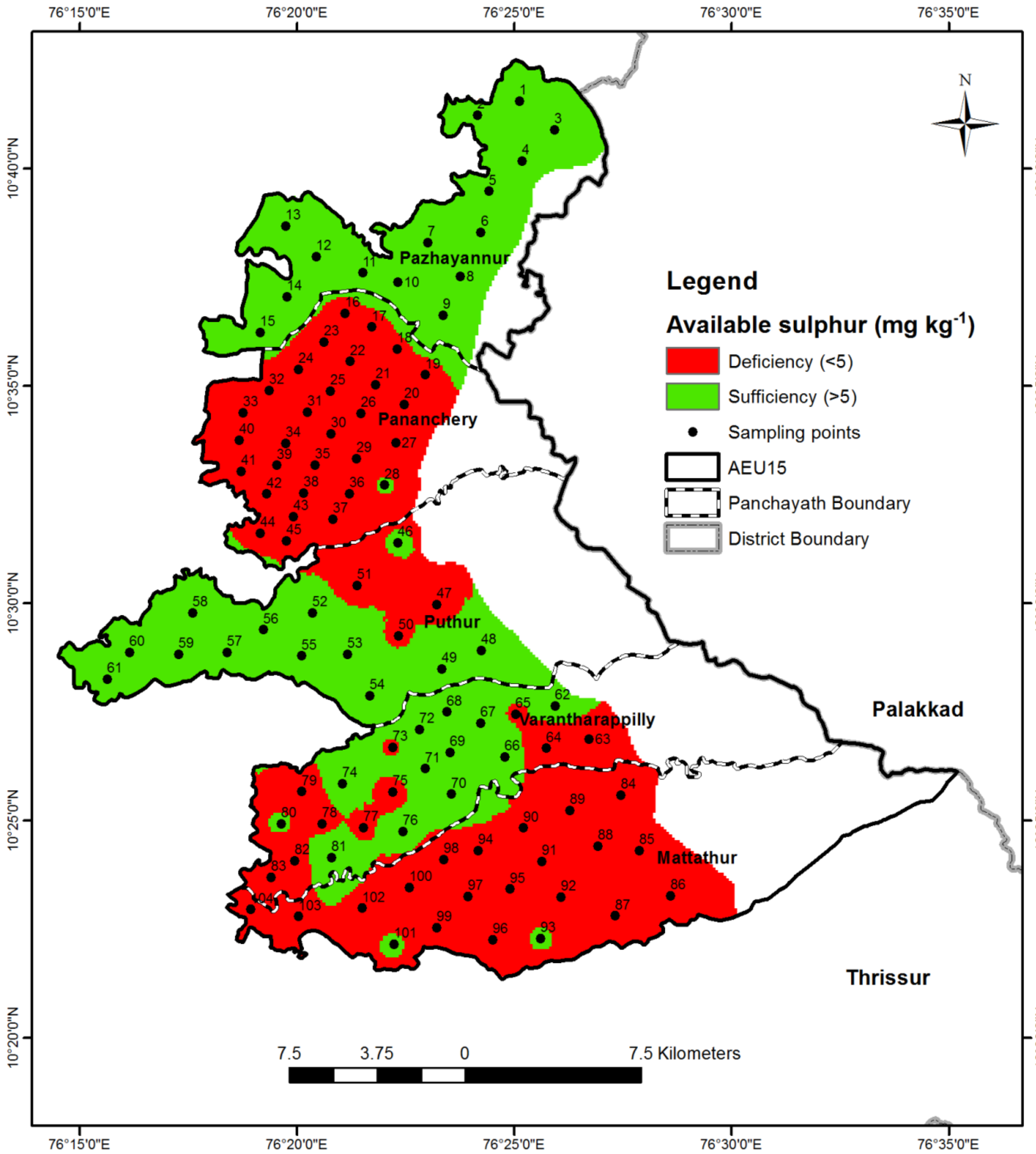


Fig 4.5 Spatial distribution of available sulphur in AEU 15 of Thrissur district of Kerala

4.5 Status of micronutrients in post flood soils of AEU 15 in Thrissur district

4.5.1 Available iron

All panchayats were found to be sufficient in available iron content in their soils and it ranged from 15.43 in Pananchery to 239.40 mg kg^{-1} in Pananchery (Table 4.33) with a mean value of 72.10 mg kg^{-1} (Appendix I). The highest mean available iron was observed in Pazhayannur panchayat (91.20 mg kg^{-1}) and the lowest in Varantharappilly panchayat (58.66 mg kg^{-1}) (Table 4.42) . Statistically there was no significant difference in available iron content between panchayats (Table 4.42).

4.5.2 Available manganese

It was observed that all the panchayats were sufficient in available manganese content in their soils. The available manganese content ranged from 6.04 mg kg^{-1} Pananchery (Table 4.33) to 117.00 mg kg^{-1} in Pananchery (Table 4.33) with an average of 37.20 mg kg^{-1} (Appendix I). As per statistical analysis ,there was significant difference between the samples in available manganese Varantharappilly and Mattathur panchayats were on par (Table 4.43). The highest mean value was observed in Pazhayannur (70.20 mg kg^{-1}) and the lowest in Mattathur panchayat (23.52 mg kg^{-1}) (Table 4.43).

4.5.3 Available copper

The panchayats under study were sufficient in terms of available copper content in their soils . The available copper contents ranged from 0.84 in Pananchery to 16.37 mg kg^{-1} in Pananchery (Table 4.33) with a mean of 4.40 mg kg^{-1}. A significant difference in available copper was reported in different panchayats Pananchery and Puthur panchayats were on par (Table 4.44). Puthur panchayat exhibited the highest mean available copper content (5.95 mg kg^{-1}) and Mattathur panchayat exhibited the lowest mean (2.55 mg kg^{-1}) (Table 4.44).

4.5.4 Available zinc

Sufficient levels of available zinc was present in all the panchayats under study. No deficiencies were noted in any of the panchayats. The available zinc content in soils ranged from 1.22 mg kg^{-1} in Pananchery (Table 4.33) to 21.57 mg kg^{-1} in

Mattathur (Table 4.36) with a mean value of 4.31 mg kg^{-1} (Appendix I). Statistically, there was no significant difference in available zinc content between different panchayats. The lowest mean available zinc content was obtained in Varantharappilly (3.66 mg kg^{-1}) and highest mean in Puthur panchayat (5.23 mg kg^{-1}) (Table 4.45).

4.5.6 Available boron

All the panchayats were deficient in terms of available boron content with boron content ranging from 0.003 in Pazhayannur (Table 4.32) to 0.298 mg kg^{-1} Puthur (Table 4.34) with a mean of 0.030 mg kg^{-1} (Appendix I) . The highest mean available boron was in Puthur panchayat (0.049 mg kg^{-1}) and the lowest mean in Pazhayannur panchayat (0.003 mg kg^{-1}) (Table 4.46). As per statistical analysis, there was no significant difference in available boron between different panchayat (Table 4.46). Spatial distribution of available boron in AEU 15 in Thrissur district of Kerala is given in Fig 4.

4.6 Biological attributes of post flood soils under AEU 15 in Thrissur district

4.6.1. Dehydrogenase activity

The dehydrogenase activity was found to vary from 0.23 μg TPF g^{-1} 24 hr^{-1} in Pananchery (Table 4.37) to 477.37 μg TPF g^{-1} 24 hr^{-1} in Mattathur (Table 4.41) with a mean value of 120.29 μg TPF g^{-1} 24 hr^{-1} (Appendix I). There was significant difference between panchayats in dehydrogenase enzyme activity. Pazhayannur, Puthur, Mattathur and Varantharappilly panchayats were on par. The highest mean value was observed in Pazhayannur panchayat (477.37 μg TPF g^{-1} 24 hr^{-1}) and lowest mean in Pananchery panchayat (60.43 μg TPF g^{-1} 24 hr^{-1}) (Table 4.47).

4.7. Soil fertility maps

Soil fertility maps of AEU 15 of Thrissur district showing spatial variation in physical, chemical and biological characters were generated using ArcGIS software . Spatial distribution maps of organic carbon content, available nitrogen, potassium, magnesium, sulphur, boron and RSQI (Relative Soil Quality Index) in AEU 15 of Thrissur district of Kerala were prepared to study the spatial variation in the study area.

Table 4.32 Micronutrient status in soils of Pazhayannur panchayat in AEU 15 of Thrissur district

Sample no.	Available iron (mg kg^{-1})	Available manganese (mg kg^{-1})	Available copper (mg kg^{-1})	Available zinc (mg kg^{-1})	Available boron (mg kg^{-1})
1	116.90	103.20	4.34	4.78	0.005
2	108.50	102.30	3.69	2.46	0.008
3	43.65	101.70	5.43	3.35	0.018
4	125.80	40.75	8.04	5.31	0.014
5	56.27	39.98	4.46	2.48	0.014
6	131.40	40.47	7.50	5.14	0.009
7	68.17	33.03	3.57	3.49	0.006
8	56.25	53.33	5.54	3.87	0.089
9	86.97	89.51	3.24	5.13	0.103
10	58.50	115.10	5.82	4.22	0.009
11	25.49	64.10	2.08	7.28	0.021
12	88.95	73.85	3.51	7.74	0.020
13	196.10	82.36	3.59	4.76	0.018
14	102.30	67.83	9.72	6.70	0.130
15	102.80	45.53	4.29	2.89	0.003

Table 4.33 Micronutrients status in soils of Pananchery panchayat in AEU 15 of Thrissur district

Sample no.	Available iron (mg kg^{-1})	Available manganese (mg kg^{-1})	Available copper (mg kg^{-1})	Available zinc (mg kg^{-1})	Available boron (mg kg^{-1})
1	52.61	30.81	8.06	11.64	0.043
2	41.64	20.81	7.17	3.58	0.054
3	119.90	37.20	8.91	4.90	0.043
4	28.16	12.80	6.18	2.71	0.018
5	15.43	10.64	5.49	2.50	0.020
6	200.60	80.08	16.37	5.64	0.021
7	94.75	61.24	8.80	5.85	0.009
8	28.59	6.04	0.84	1.22	0.008
9	66.24	117.00	12.29	4.80	0.006
10	63.03	33.77	7.32	3.15	0.005
11	140.80	37.89	5.50	3.24	0.026
12	32.06	32.72	5.06	2.64	0.009
13	38.40	43.93	3.63	2.65	0.014
14	151.40	27.87	4.06	2.43	0.020
15	160.60	89.58	6.25	7.74	0.011
16	79.54	39.70	4.17	3.00	0.029
17	239.40	41.94	3.60	3.90	0.028
18	72.63	14.31	6.31	2.74	0.005
19	57.31	32.93	3.75	3.46	0.021
20	65.02	40.14	2.60	2.98	0.012
21	18.83	13.97	1.05	7.55	0.026
22	20.94	22.27	3.25	2.78	0.012
23	34.44	32.05	3.96	2.45	0.072
24	89.53	32.68	3.20	2.85	0.072
25	22.21	16.32	5.49	3.01	0.025
26	55.99	30.58	4.19	3.70	0.014
27	81.01	46.96	3.33	1.87	0.023
28	52.49	34.36	4.31	2.85	0.025
29	24.99	41.01	1.71	2.45	0.006
30	47.34	41.27	3.57	3.46	0.051

Table 4.34 Micronutrient status in soils of Puthur panchayat in AEU 15 of Thrissur district

Sample no.	Available iron (mg kg^{-1})	Available manganese (mg kg^{-1})	Available copper (mg kg^{-1})	Available zinc (mg kg^{-1})	Available boron (mg kg^{-1})
1	29.19	59.02	2.55	2.35	0.081
2	58.57	12.84	8.27	8.09	0.058
3	47.68	13.29	5.49	3.88	0.034
4	88.47	58.91	12.38	14.30	0.038
5	32.31	43.62	3.88	4.99	0.023
6	86.14	102.70	6.15	7.01	0.032
7	54.54	28.92	10.46	9.41	0.011
8	104.20	39.57	11.70	8.22	0.046
9	65.47	17.96	3.08	2.10	0.008
10	74.54	22.63	4.35	3.19	0.012
11	125.40	25.51	5.77	3.90	0.298
12	72.94	47.10	2.84	1.87	0.012
13	108.00	72.71	4.63	3.98	0.028
14	97.04	59.42	6.34	5.06	0.008
15	77.58	36.78	3.74	2.80	0.072
16	19.15	13.98	3.50	2.58	0.025

Table 4.35 Micronutrient status in soils of Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	Available iron (mg kg^{-1})	Available manganese (mg kg^{-1})	Available copper (mg kg^{-1})	Available zinc (mg kg^{-1})	Available boron (mg kg^{-1})
1	43.36	16.24	2.53	2.88	0.006
2	62.74	15.15	3.31	1.89	0.005
3	23.38	10.85	2.69	2.83	0.029
4	75.16	12.73	5.46	5.00	0.045
5	28.01	18.89	3.74	6.34	0.058
6	28.67	29.31	3.29	2.30	0.017
7	22.52	12.38	3.73	3.25	0.087
8	37.36	23.88	3.85	3.59	0.023
9	60.39	28.01	3.06	3.79	0.006
10	38.63	23.75	2.61	5.20	0.014
11	76.73	42.03	4.82	4.82	0.005
12	32.43	14.84	1.84	2.06	0.005
13	50.42	36.32	2.44	3.14	0.009
14	120.20	45.18	1.93	3.87	0.028
15	50.47	25.52	2.76	2.59	0.025
16	41.47	9.76	2.15	2.89	0.009
17	98.95	36.54	5.09	1.38	0.011
18	100.40	37.20	2.35	5.85	0.028
19	75.06	30.41	4.26	3.66	0.028
20	40.77	10.36	3.53	3.62	0.023
21	67.63	22.07	3.87	4.65	0.029
22	115.70	42.61	4.33	4.85	0.011

Table 4.36 Micronutrient status in soils of Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	Available iron (mg/kg)	Available managanese (mg/kg)	Available copper (mg/kg)	Available zinc (mg/kg)	Available boron (mg/kg)
1	140.30	61.38	3.43	9.59	0.061
2	138.30	21.25	2.31	2.67	0.037
3	32.43	16.18	1.66	4.74	0.015
4	55.94	10.95	1.66	2.73	0.074
5	66.83	10.69	2.28	2.68	0.061
6	28.66	13.75	2.85	1.83	0.018
7	54.37	59.55	1.96	2.46	0.026
8	79.23	11.41	2.43	1.50	0.046
9	88.43	12.08	2.05	1.59	0.028
10	31.95	40.90	3.50	4.96	0.029
11	31.59	14.21	1.23	7.79	0.020
12	57.29	23.58	2.94	4.99	0.028
13	23.71	11.38	3.71	4.28	0.005
14	25.54	26.08	4.19	5.73	0.026
15	73.70	18.45	2.51	5.92	0.031
16	57.14	30.75	2.92	21.57	0.021
17	68.51	16.36	1.52	3.69	0.005
18	127.00	31.79	3.19	3.66	0.017
19	79.66	24.50	1.96	2.30	0.028
20	189.30	21.93	3.19	4.15	0.014
21	52.98	16.81	1.96	2.37	0.040

Table 4.37 Dehydrogenase activity in soils of Pazhayannur panchayat in AEU 15 in Thrissur district

Sample no.	Dehydrogenase activity (μg TPF g $^{-1}$ 24 hr^{-1})
1	112.49
2	88.78
3	178.03
4	102.26
5	262.16
6	249.14
7	145.95
8	161.29
9	84.13
10	92.03
11	165.48
12	298.41
13	371.39
14	289.58
15	191.51

Table 4.38 Dehydrogenase activity in soils of Pananchery panchayat in AEU 15 of Thrissur district

Sample no.	Dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1})
1	28.61
2	2.32
3	40.56
4	45.90
5	91.79
6	47.02
7	208.09
8	1.94
9	18.27
10	71.57
11	84.71
12	274.79
13	0.78
14	23.83
15	0.23
16	14.63
17	37.75
18	62.69
19	21.75
20	10.48
21	11.01
22	11.44
23	18.29
24	9.87
25	17.05
26	3.90
27	10.61
28	20.68
29	11.74
30	14.30

Table 4.39 Dehydrogenase activity in soils of Puthur panchayat in AEU 15 of Thrissur district

Sample no.	Dehydrogenase activity (μg TPF g^{-1} 24 hr^{-1})
1	158.50
2	192.43
3	21.85
4	98.54
5	82.27
6	67.86
7	114.35
8	147.81
9	192.43
10	54.18
11	379.29
12	74.37
13	330.49
14	273.78
15	62.75
16	46.02

Table 4.40 Dehydrogenase activity in soils of Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	Dehydrogenase activity (μg TPF g^{-1} 24 hr^{-1})
1	2.79
2	74.84
3	218.46
4	166.41
5	92.50
6	99.47
7	194.29
8	145.95
9	191.51
10	379.29
11	28.35
12	23.71
13	98.54
14	147.81
15	28.35
16	37.65
17	10.88
18	85.53
19	202.66
20	219.39
21	82.74
22	186.39

Table 4.41 Dehydrogenase activity in soils of Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	Dehydrogenase activity (μg TPF g^{-1} 24 hr^{-1})
1	189.18
2	220.79
3	169.66
4	236.59
5	186.86
6	46.95
7	154.78
8	80.88
9	172.45
10	252.86
11	164.08
12	127.36
13	39.04
14	178.49
15	77.16
16	384.41
17	195.22
18	477.37
19	45.09
20	28.35
21	58.57

Table 4. 42 Mean, range and standard deviation of available iron content (mg kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available iron	
	Range	Mean ± SD
Pazhayannur	25.49- 196.10	91.20±42.83
Pananchery	15.43 – 239.40	73.20 ± 55.97
Puthur	19.15 – 125.4	71.33 ± 30.17
Varantharappilly	22.52 – 120.20	58.66±29.51
Mattathur	23.71 – 189.30	71.56 ± 44.05

Table 4.43 Mean, range and standard deviation of available manganese content (mg kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available manganese	
	Range	Mean ± SD
Pazhayannur	33.03 - 115.10	70.20^{a} ±27.57
Pananchery	6.04 -117.00	37.43^{bc} ± 23.69
Puthur	12.84 – 102.70	40.94^{b} ± 25.04
Varantharappilly	9.76 - 45.18	24.73^{c} ±11.45
Mattathur	10.69 – 61.38	23.52^{c} ± 14.62
CD(0.05) = 15.161		

Means followed by different letters in the same column are significantly different at P= 0.05.

Table 4.44 Mean, range and standard deviation of available copper content (mg kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available copper	
	Range	Mean ± SD
Pazhayannur	2.08 – 9.72	4.99^{ab} ±2.07
Pananchery	0.84 – 16.37	5.34^{a} ± 3.23
Puthur	2.55 – 12.38	5.95^{a} ± 3.16
Varantharappilly	1.84 – 5.46	3.35^{bc} ±1.02
Mattathur	1.23 – 4.19	2.55^{c} ± 0.80
CD(0.05) = 1.703		

Table 4.45 Mean, range and standard deviation of available zinc content (mg kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available zinc	
	Range	Mean ± SD
Pazhayannur	2.46 – 7.74	4.64^{a}±1.65
Pananchery	1.22 – 11.64	3.79^{a} ± 2.11
Puthur	1.87 – 14.30	5.23^{a} ± 3.38
Varantharappilly	1.38 – 6.34	3.66^{a} ±1.31
Mattathur	1.5 – 21.57	4.80^{a} ± 4.36

Means followed by different letters in the same column are significantly different at P= 0.05 means followed by same letters are non-significant.

Table 4.46 Mean, range and standard deviation of available boron content (mg kg^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Available boron	
	Range	Mean ± SD
Pazhayannur	0.003 – 0.130	0.031^{a}±0.04
Pananchery	0.005 – 0.072	0.024^{a}± 0.02
Puthur	0.008 – 0.298	0.049^{a}± 0.07
Varantharappilly	0.005 – 0.087	0.023^{a}±0.02
Mattathur	0.005 – 0.074	0.030^{a}±0.02

Table 4.47 Mean, range and standard deviation of dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) of soils in AEU 15 of Thrissur district

Panchayat	Dehydrogenase activity	
	Range	Mean ± SD
Pazhayannur	84.13 – 371.39	186.18^{a} ±89.17
Pananchery	0.23 – 274.79	40.55^{b} ± 60.43
Puthur	21.85 – 379.29	143.56^{a} ± 105.98
Varantharappilly	2.79 – 379.29	123.52^{a} ±91.74
Mattathur	28.35 – 477.37	166.01^{a} ± 112.78
CD(0.05) = 65.807		

Means followed by different letters in the same column are significantly different at P= 0.05 means followed by same letters are non-significant. Summary statistics of soil properties of all five panchayats in AEU 15 of Thrissur district is also presented (Appendix VI).

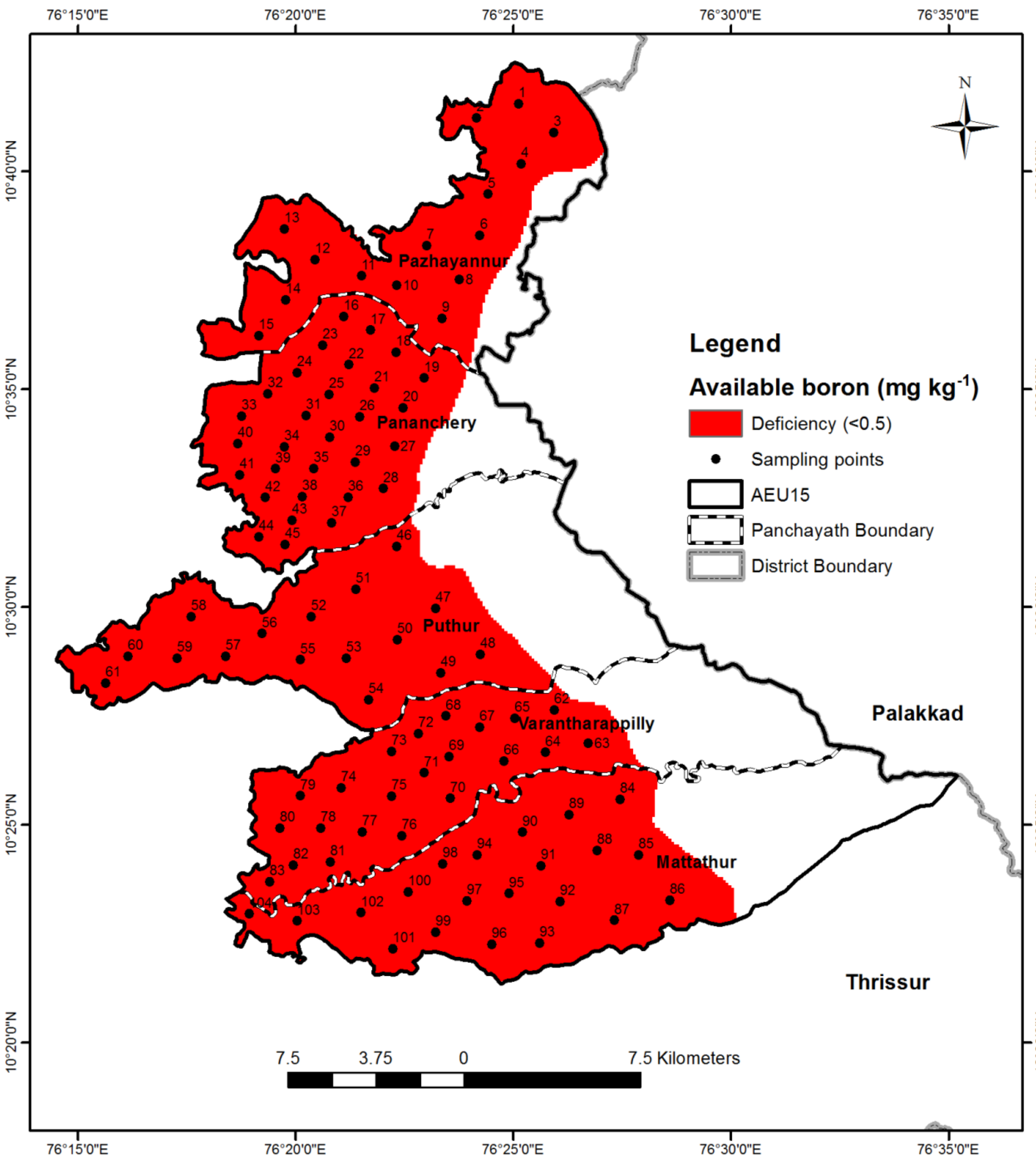


Fig 4.6 Spatial distribution of available boron in AEU 15 of Thrissur district of Kerala

4.7 Correlation between soil properties

Correlation between different physical, chemical and biological properties were obtained (Table 4.49). A significant and strong negative correlation (r = -0.804**) was observed between bulk density and porosity. Maximum water holding capacity showed a significant and positive correlation with organic carbon (r = 0.268*) and available potassium (r = 0.248). A significant negative correlation (r = -0.318**) was found between soil pH and exchangeable acidity.

Organic carbon in soil had a positive and significant correlation with available nitrogen (r = 0.226*), available zinc (r=0.213*), maximum water holding capacity (r=0. 268**), available magnesium (r = 0.205*), available copper (r=0.193*) and dehydrogenase activity (r=0.239*) and a negative significant correlation with particle density (r = -0.194*).

Available potassium in soils exhibited a significant positive correlation (r = 0.245*) with available phosphorus.

Available phosphorus had a positive and significant relationship with available potassium (r=0.245*), available sulphur(r=0.207*) and dehydrogenase activity (r=0.223*).

A significant positive correlation was observed for available calcium with available magnesium (r = 0.479**) and available zinc (r = 0.463**).There was a significant positive correlation of available magnesium with available calcium (r= 0.479**) , managanese (r=0.238*) and copper (r=0. 425**).Simple correlation studies indicate that there exists a significant and positive correlation of available sulphur with available phosphorus(r= 0.207*), manganese (r= 0.330**) and dehydrogenase activity (r = 0.364**).

Available iron exhibited a positive and significant correlation with available copper (r = 0.298**) and available manganese (r = 0.376**) and a negative correlation with available potassium (r = -0.229*).

Available zinc exhibited positive correlation with pH, exchangeable acidity, electrical conductivity , organic carbon, available manganganese, copper and dehydrogenase activity.

Available boron showed positive correlation with dehydrogenase activity ($r=0.238^{*}$).

Dehydrogenase activity showed a significant and positive correlation with organic carbon ($r = 0.239^{*}$) , available phosphorus ($r = 0.223^{*}$) and available calcium ($r = 0.216^{*}$), pH, electrical conductivity, available sulphur, zinc and boron . EC has a positive correlation with pH ($r = 0.426^{**}$) and a significant negative correlation ($r = -0.199^{*}$) with exchangeable acidity.

Table 4.48 Correlation between physical , chemical and biological parameters

	BD	Moistue	PD	Porosity	WHC	pH	EA	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B	DHA
BD	1	-0.412**	0.124	-0.804**	-0.132	0.134	-.233*	0.141	-0.126	0.146	.196*	0.08	0.109	-0.102	0.022	-0.012	-0.032	0.053	0.085	0.074	0.13
Moisture		1	-0.313**	0.175	0.225*	-0.243*	0.135	-0.133	0.221*	0.083	-0.098	0.047	0.134	.401**	-0.033	0.039	0.07	.194*	0.008	0.09	-0.09
PD			1	0.484**	-0.09	0.174	-0.05	0.179	-.194*	-0.036	0.181	-0.137	-.233*	-.213*	0.164	0.103	0.013	-.219*	-0.045	0.046	0.078
Porosity				1	0.066	-0.011	0.18	-0.013	-0.017	-0.147	-0.061	-0.147	-.236*	-0.04	0.078	0.061	0.029	-0.185	-0.1	-0.035	-0.083
MWHC					1	-.220*	0.033	0.124	.268**	-0.043	0.183	.248*	-0.085	0.09	0.071	-0.116	0.034	-0.012	-0.009	0.085	-0.043
pH						1	-.318**	.426**	-0.057	-0.037	0.055	0.011	.379**	0.044	0.029	0	-0.033	0.022	.338**	0.043	.264**
EA							1	-.199*	-0.039	-0.117	-0.05	.221*	-.196*	-0.01	0.037	-0.067	0.064	-0.049	-.226*	-0.022	-0.154
EC								1	0.007	-0.058	.312**	0.167	.228*	-0.08	.342**	0.192	.291**	-0.004	.373**	0.178	.423**
OC									1	.226*	0.054	0.032	0.134	.205*	-0.004	0.123	0.165	.193*	.213*	-0.072	.239*
N										1	-0.032	-0.089	.212*	0.066	-0.121	0.118	0.094	0.059	0.046	-0.122	0.1
P											1	.245*	-0.068	-0.144	.207*	0.084	-0.115	-0.106	0.115	0.141	.223*
K												1	0.045	-0.008	0.057	-.229*	-0.09	-0.101	-0.016	0.128	0.146
Ca													1	.479**	-0.189	-0.004	0.013	0.172	.463**	0.026	.216*
Mg														1	0.095	0.032	.238*	.425**	0.17	0.07	-0.032
S															1	0.141	.330**	0.074	0.01	0.128	.364**
Fe																1	.376**	.298**	0.11	0.081	0.15
Mn																	1	.365**	.197*	-0.027	0.084
Cu																		1	.346**	0.087	-0.03
Zn																			1	0.06	.268**
B																				1	.238*
DHA																					1

** Correlation is significant at the 0.01 level

* Correlation is significant at the 0.05 level

4.8. Formulation of a minimum data set and assessment of soil quality index

The results of individual soil parameters were subjected to Principal Component Analysis to get a MDS (Minimum Data Set) using the SPSS window version 16.0 (SPSS Inc., Chicago, USA). Treatment means were separated by Duncan Multiple Range Test at 5 per cent and 1 per cent level of significance. A Pearson's correlation matrix was constructed among the soil physical, chemical and biological properties of soils.

4.8.1. Formulation of a minimum data set (MDS)

To formulate a minimum data set for assessing soil quality, 21 soil parameters were analysed using PCA. The parameters that were used were bulk density, soil moisture content , particle density, porosity, maximum water holding capacity, pH, exchangeable acidity, electrical conductivity, organic carbon, available primary nutrients like nitrogen, phosphorus and potassium , secondary nutrients like available calcium, magnesium and sulphur ,micronutrients like iron, manganese, copper, zinc and boron and dehydrogenase activity.

The Principal component analysis extracted seven principal components (Table 4.51) with eigen values greater than one and they were used for selecting soil quality indicators in MDS. The seven principal components namely PC 1, PC 2, PC 3, PC 4, PC 5, PC 6 and PC 7 explained 14.69%, 12.54%, 10.40 %, 9.36 % , 7.50 % , 6.04% and 4.82% of total variance (65.37%) respectively (Table 4.50).

The factor loading (Table 4.49) of the parameters in each of the PC group indicates the contribution of that parameter to the particular PC group. Only highly weighted variables (i.e, having absolute values of factor loading within 10% of the highest factor loading in the PC group) were retained from each PC for MDS generation (Andrews *et al*., 2002). When more than one parameter was retained under a single PC group , multivariate correlation coefficients (Table 4.50) were used to set the MDS (Andrews *et al.*, 2002). Those soil parameters in a particular PC group , with a correlation coefficient less than 0.6 (r <0.6) were all retained in the PC group. If the parameters were well correlated (r >0.6), the one with highest absolute value of factor loading was chosen for MDS.

In the first PC group, soil pH had the highest factor loading (Table 4.49), so it was chosen for MDS (Table 4.51) whereas in the second PC group , available magnesium was chosen. In the third PC group, bulk density and porosity had a correlation, r >0.6, therefore, porosity with the highest factor loading was chosen in the MDS. In the fourth PC group, available manganese was chosen. In the fifth PC group, maximum water holding capacity and available potassium had correlation, r >0.6, therefore available potassium with highest factor loading was chosen in fifth PC group for formation of MDS. Available nitrogen and available boron were retained in the sixth and the seventh PC group respectively. The final list of MDS parameters are given in Table 4.51.

Table 4.49 Results of principal component (PC) analysis showing factor loadings under various principal component groups

Parameters	Components						
	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Bulk density	0.106	-0.185	-0.884	0.023	-0.130	0.035	0.149
Moisture content	-0.179	0.608	0.388	-0.050	0.247	0.187	0.158
Particle density	0.108	-0.579	0.297	0.149	-0.351	-0.051	0.244
Porosity	-0.028	-0.185	**0.955**	0.059	-0.094	-0.069	0.018
MWHC	-0.072	0.082	0.161	0.066	0.625	0.127	0.162
pH	**0.772**	-0.083	-0.011	-0.088	-0.230	-0.163	-0.027
Exchangeable acidity	-0.346	-0.035	0.059	0.019	0.575	-0.008	-0.159
EC	0.674	-0.195	-0.023	0.384	0.141	-0.065	0.205
Organic carbon	0.130	0.196	0.112	0.152	0.353	0.648	-0.122
Available N	0.003	0.022	-0.144	-0.085	-0.171	**0.777**	-0.031
Available P	0.180	-0.341	-0.113	0.073	0.265	0.155	0.522
Available K	0.164	-0.025	-0.170	-0.123	**0.663**	-0.163	0.168
Available Ca	0.644	0.488	-0.122	-0.271	-0.101	0.182	-0.017
Available Mg	0.155	**0.772**	0.087	0.074	-0.031	0.021	0.064
Available S	0.117	-0.129	0.035	0.673	0.174	-0.195	0.210
Available Fe	-0.031	0.059	0.049	0.560	-0.359	0.331	0.209
Available Mn	0.084	0.220	0.018	**0.791**	-0.048	0.072	-0.195
Available Cu	0.033	0.634	-0.172	0.425	-0.161	0.056	-0.005
Available Zn	0.668	0.257	-0.056	0.143	-0.032	0.140	-0.034
Available B	0.022	0.183	-0.033	0.025	0.010	-0.174	**0.813**
DHA	0.513	-0.174	-0.073	0.237	0.186	0.246	0.290

Table 4.50 Eigen values, their percentage variance and cumulative variance

Particulars	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Eigen values	3.086	2.633	2.184	1.965	1.575	1.270	1.012
% variance	14.69	12.54	10.40	9.36	7.50	6.04	4.82
Cumulative variance	14.69	27.24	37.64	46.99	54.50	60.54	65.37

Table 4.51 Minimum Data Set (MDS) extracted for soil quality analysis

PC1	PC2	PC3	PC4	PC5	PC6	PC7
pH	Available magnesium	Porosity	Available manganese	Available potassium Maximum water holding capacity	Available nitrogen	Available boron

Table 4.52 Weightage factors of different PC groups

PCs	1	2	3	4	5	6	7
Weights (Wi)	0.22	0.19	0.16	0.14	0.11	0.09	0.07

4.3.2. Assessment of soil quality index

After selection of the MDS parameters, the variables in the MDS were transformed into a dimensionless value called 'score' based on their functions in soil. Accordingly, they were classified as 'more is better' ,'optimum' or 'less is better' function. Maximum water holding capacity, porosity, available magnesium, potassium, nitrogen and boron were grouped as 'more is better' function, pH was considered as an 'optimum' function whereas available manganese was grouped under 'less is better' function. Here, non linear scoring method was used for scoring in this study.

The non-linear scoring indices were chosen as they represented soil function better than linear scoring indices because of their higher F values and CV, which expressed their better differentiating ability of the SQI calculation (Yu *et al.*,2018). The following sigmoidal function was used for non linear scoring:

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

where S_{NL} is the non-linear score of the soil indicator, a is the maximum score of the function (here a = 1) , X is the soil indicator value, X_m is the mean value of each soil indicator, and b is the slope of the equation which is laid as −2.5 for a 'more is better' curve and 2.5 for a 'less is better' curve (Raiesi,2017; Yu *et al.*,2018).

Further, the transformed indicator scores were integrated into a comparative SQI using weighted additive method as follows:

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

where S_i is the non-linear indicator score, n is the number of soil indicators in the MDS, and W_i is the weightage value of soil indicators (Andrews *et al*., 2002; Askari and Holden, 2014; Yu *et al*.,2018). Weightage value was obtained by calculating the ratio of the variance (%) of a particular PC group to the total variance (%). The SQI calculated for each sampling sites of different panchayats are given in Table 4.

The soil quality values ranged from 0.33 in Pananchery (Table 4.54) to 0.71 in Pananchery (Table 4.54). The highest mean SQI was observed in Varantharappilly (0.57) and lowest mean in Pazhayannur (0.52) (Table 4.58).

4.4 Computation of relative soil quality index and nutrient index

4.4.1 Relative soil quality index

Relative soil quality index was calculated using the following formula proposed by Karlen and Stott (1994) :

$$RSQI = \frac{SQI_{\text{computed}}}{SQI_{\text{theoretical maximum}}} \times 100$$

The maximum theoretical value of SQI was obtained as 0.91 by multiplying respective weightage factor and maximum score of different MDS parameters.The RSQI values for different panchayats are given in the Table 4.53, 4.54, 4.55, 4.56 and 4.57. Highest RSQI value was observed in Pananchery panchayat (78.13%) and also the lowest in the same panchayat (35.65%) (Table 4.53). The highest mean RSQI was recorded in Varantharappilly panchayat (61.81%) and lowest in Pananchery panchayat (48.17%) (Table 4.59). About 11.53% of the samples were rated as belonging to the ‘poor’ category (RSQI <50%) , 81.73% of the samples as ‘medium’

(RSQI = 51-75%) and 6.73% of the soil samples as ‘good’ (RSQI > 75%). Spatial distribution of RSQI in AEU 15 of Thrissur district of Kerala is given in Fig 4.7.

4.4.2 Nutrient index (NI)

Nutrient index is a measure of nutrient supplying capacity of soils to plants (Parker *et al.*,1951; Shetty *et al.*, 2008; Pathak, 2010); Kumar *et al*, 2013 and Ravi Kumar and Somashekar, 2013). Based on samples in high, medium and low category , this index helps in measuring fertility status of soils.The following formula was used :

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

L is the number of samples in low category, M is the number of samples in medium category, H is the number of samples in high category and N is the total number of samples. Ramamurthy and Bajaj (1969) classified fertilitiy of soils into three classes viz; if the NI < 1.67 - low fertility, NI is between 1.67 to 2.33 - medium fertility, NI> 2.33 - high fertility. Panchayat wise nutrient index was calculated for organic carbon, available nitrogen , available phosphorus and available potassium (Tables 4.60, 4.61, 4.62, 4.63 and 4.64).

Nutrient index for organic carbon was rated as low (NI <1.67) for Pananchery (Table 4.61), Puthur (Table 4.62) and Mattathur (Table 4.64) and medium for Pazhayannur (Table 4.60) and Varantharappilly panchayats (Table 4.63). All the panchayats showed a low nutrient index (NI <1.67) for available nitrogen. In case of available phosphorus, all the panchayats showed a remarkable high nutrient index (NI >2.33) with the highest NI in Pazhayanur (Table 4.60), Puthur (Table 4.62) and Varathirappilly panchayat (NI = 3) (Table 4.63) and lowest in Pananchery (NI = 2.5) (Table 4.61). Nutrient index for available potassium was high (NI > 2.33) for Puthur (NI=2.5) (Table 4.62) and Varantharappilly (NI=2.45) panchayat (Table 4.63). whereas it was medium for Pazhayannur (Table 4.60) (NI=2.2), Pananchery (NI=1.97) and Mattathur (NI=2.19) (Table 4.64).

Table 4.53 Soil quality index (SQI), relative soil quality index (RSQI) and ratings for Pazhayannur panchayat

Sample no.	Soil quality index	Relative soil quality index (%)	Rating
1	0.46	50.60	Medium
2	0.36	39.87	Poor
3	0.50	55.14	Medium
4	0.48	52.86	Medium
5	0.54	59.58	Medium
6	0.57	62.01	Medium
7	0.57	61.81	Medium
8	0.60	65.63	Medium
9	0.52	57.29	Medium
10	0.48	52.00	Medium
11	0.49	53.45	Medium
12	0.57	62.49	Medium
13	0.47	51.65	Medium
14	0.59	64.92	Medium
15	0.53	57.65	Medium

Table 4.54 Soil quality index (SQI), relative soil quality index (RSQI) and ratings for Pananchery panchayat

Sample no.	Soil quality index	Relative soil quality index (%)	Rating
1	0.60	66.15	Medium
2	0.53	58.18	Medium
3	0.60	65.42	Medium
4	0.69	75.51	Good
5	0.71	78.13	Good
6	0.42	45.70	Poor
7	0.40	43.35	Poor
8	0.62	67.98	Medium
9	0.49	53.41	Medium
10	0.50	54.97	Medium
11	0.57	62.38	Medium
12	0.53	58.10	Medium
13	0.41	45.16	Poor
14	0.46	50.66	Medium
15	0.57	61.97	Medium
16	0.55	60.19	Medium
17	0.46	50.30	Medium
18	0.62	68.15	Medium
19	0.60	65.82	Medium
20	0.57	62.39	Medium
21	0.52	57.35	Medium
22	0.42	46.37	Poor
23	0.61	66.99	Medium
24	0.55	59.69	Medium
25	0.62	67.32	Medium
26	0.45	49.58	Poor
27	0.33	35.65	Poor
28	0.44	48.08	Poor
29	0.44	47.62	Poor
30	0.51	55.97	Medium

Table 4.55 Soil quality index (SQI), relative soil quality index (RSQI) and ratings for Puthur panchayat in AEU 15 of Thrissur district

Sample no.	SQI	RSQI (%)	Rating
1	0.56	61.42	Medium
2	0.67	72.75	Good
3	0.60	65.90	Medium
4	0.60	65.28	Medium
5	0.54	58.95	Medium
6	0.54	58.93	Medium
7	0.54	58.98	Medium
8	0.55	60.62	Medium
9	0.58	63.58	Medium
10	0.48	52.77	Medium
11	0.64	70.00	Medium
12	0.51	55.38	Medium
13	0.50	55.11	Medium
14	0.41	44.31	Poor
15	0.55	60.51	Medium
16	0.64	70.07	Good

Table 4.56 Soil quality index (SQI), relative soil quality index (RSQI) and ratings in Varantharappilly panchayat in AEU 15 of Thrissur district

Sample no.	SQI	RSQI (%)	Rating
1	0.51	56.19	Medium
2	0.53	57.67	Medium
3	0.54	59.48	Medium
4	0.66	72.47	Good
5	0.66	71.67	Good
6	0.60	66.01	Medium
7	0.60	65.36	Medium
8	0.67	73.18	Good
9	0.45	49.00	Poor
10	0.52	57.32	Medium
11	0.49	53.56	Medium
12	0.52	57.01	Medium
13	0.53	57.89	Medium
14	0.50	54.93	Medium
15	0.57	62.55	Medium
16	0.61	66.89	Medium
17	0.53	57.70	Medium
18	0.57	62.82	Medium
19	0.62	68.22	Medium
20	0.65	71.40	Medium
21	0.61	67.09	Medium
22	0.47	51.40	Medium

Table 4.57 Soil quality index (SQI), relative soil quality index (RSQI) and ratings for Mattathur panchayat in AEU 15 of Thrissur district

Sample no.	SQI	RSQI (%)	Rating
1	0.59	65.04	Medium
2	0.52	56.97	Medium
3	0.52	57.33	Medium
4	0.60	65.39	Medium
5	0.58	63.60	Medium
6	0.62	68.08	Medium
7	0.43	46.96	Poor
8	0.50	54.41	Medium
9	0.51	55.83	Medium
10	0.48	52.53	Medium
11	0.51	56.22	Medium
12	0.58	63.75	Medium
13	0.53	57.59	Medium
14	0.59	64.60	Medium
15	0.53	58.21	Medium
16	0.57	62.57	Medium
17	0.59	64.93	Medium
18	0.53	58.02	Medium
19	0.54	59.48	Medium
20	0.49	53.95	Medium
21	0.57	62.62	Medium

Table 4.58 Mean, range and standard deviation of soil quality index (SQI) values of AEU 15 in Thrissur district

Panchayat	SQI	
	Range	Mean±SD
Pazhayannur	0.36-0.60	0.52±0.06
Pananchery	0.33-0.71	0.53±0.09
Puthur	0.41-0.67	0.56±0.07
Varantharappilly	0.45-0.67	0.57±0.07
Mattathur	0.43-0.62	0.54±0.05

Table 4.59 Mean, range and standard deviation of relative soil quality index of soils in AEU 15 of Thrissur district

Panchayat	RSQI (%)	
	Range	Mean±SD
Pazhayannur	39.87- 64.92	56.46±6.76
Pananchery	35.65 – 78.13	48.17±8.37
Puthur	44.31- 72.75	60.91±7.19
Varantharappilly	49.00-73.18	61.81±7.16
Mattathur	46.96- 68.08	59.43±5.26

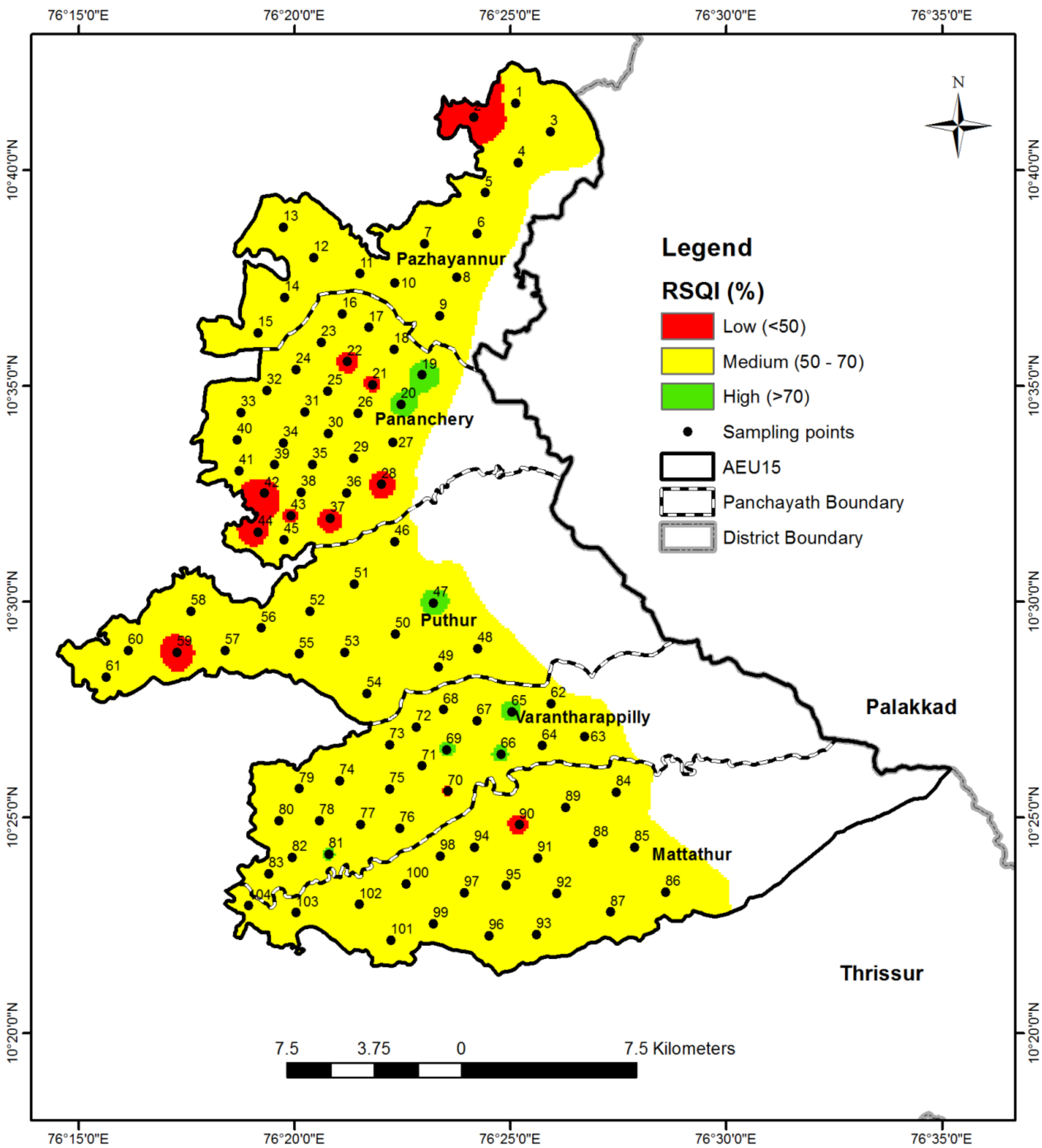


Fig 4.7 Spatial distribution of RSQI in AEU 15 of Thrissur district of Kerala

Table 4.60 Nutrient indices of Pazhayannur panchayat for organic carbon and primary nutrients in AEU 15 of Thrissur district

Parameters	Nutrient Index	Remarks
Organic carbon	1.87	Medium
Available nitrogen	1.00	Low
Available phosphorus	3.00	High
Available potassium	2.20	Medium

Table 4.61 Nutrient indices of soils of Pananchery panchayat for organic carbon and primary nutrients in AEU 15 of Thrissur district

Parameters	Nutrient Index	Remarks
Organic carbon	1.6	Low
Available nitrogen	1.06	Low
Available phosphorus	2.5	High
Available potassium	1.97	Medium

Table 4.62 Nutrient indices of soils of Puthur panchayat for organic carbon and primary nutrients in AEU 15 of Thrissur district

Parameters	Nutrient Index	Remarks
Organic carbon	2.00	Medium
Available nitrogen	1.00	Low
Available phosphorus	3.00	High
Available potassium	2.45	High

Table 4.63 Nutrient indices of soils of Varantharappilly panchayat for organic carbon and primary nutrients in AEU 15 of Thrissur district

Parameters	Nutrient Index	Remarks
Organic carbon	1.38	Low
Available nitrogen	1.00	Low
Available phosphorus	3.00	High
Available potassium	2.50	High

Table 4.64 Nutrient indices of soils of Mattathur panchayat for organic carbon and primary nutrients in AEU 15 of Thrissur district

Parameters	Nutrient index	Remarks
Organic carbon	1.62	Low
Available nitrogen	1.00	Low
Available phosphorus	2.90	High
Available potassium	2.19	Medium

DISCUSSION

5. DISCUSSION

The post flood study was aimed at assessing soil quality of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping the flood affected areas using GIS where representative geo referenced surface soil samples from identified post flood areas of AEU 15 were collected. Soil physical ,chemical and biological properties of the study area were analysed. Principal component analysis (PCA) was conducted and a minimum data set (MDS) was extracted which were given appropriate scoring and weightage to finally arrive at a soil quality index. The results of the study were presented in the previous chapter which would be discussed here.

5.1 Physical attributes of soil

5.1.1 Bulk density

Bulk density ranged from 0.83 (Varantharappilly) (Table 4.5) to 1.74 Mg m^{-3} (Mattathur) (Table 4.6) with a mean value of 1.33 Mg m^{-3}. Percentage distribution of soil samples based on bulk density (Mg m^{-3}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig.5.1. About 19.23% of soils had a bulk density less than 1.20 Mg m^{-3}, 48.08% of them had bulk densities between 1.20 – 1.40 Mg m^{-3}, 29.81% of them had a range of 1.40 – 1.60 Mg m^{-3} and a mere 2.88% of them had a bulk density greater than 1.6 Mg m^{-3} with the highest value reaching 1.74 Mg m^{-3}.

The high values of bulk density might have been due to lack of adequate organic matter in the soils due to surface run off during heavy rainfall and floods. Organic matter in soils improve soil aggregation thereby decreasing bulk density of soils. This is in conformity with the results of Avnimelech *et al*. (2001), Pravin *et al*. (2013), Prabhavati *et al*. (2015), Rakshit *et al*. (2018) and Vashisht *et al*. (2020).

5.1.2 Particle density

The particle density of soils is an important soil attribute used in the calculation of porosity and void ratio (Schjonning *et al*. 2017). Usually, particle density ranges between 2.6 – 2.7 Mg m^{-3} in mineral soils (ISSS, 2015). The particle density in the AEU varied from 2.04 Mg m^{-3} (Pananchery) (Table 4.3) to 2.99 Mg m^{-3} Puthur (Table 4.5) and Mattathur (Table 4.6) with a mean value of 2.5 Mg m^{-3} .

It was observed that about 4.81% of the samples had a particle density less than 2.2 Mg m^{-3}, 27.88% of them were in the range of 2.2- 2.4 Mg m^{-3}, 39.42% in the range of 2.4- 2.6 Mg m^{-3} and 27.88% of the samples had a particle density greater than 2.6 Mg m^{-3}. The variations in particle density might be due to differences in mineralogical composition and organic matter content in the study area as quoted by Patil and Dasog (2016) and Raghunath (2017).

In the present study, a significant negative correlation ($r = -0.194$, $p < 0.05$) was observed between organic carbon content and particle density (Table 4.48). Also, deposition of sand with varying mineral composition and removal of clay during floods might have contributed to the higher particle density of soil for a few samples in different panchayats. A similar trend was also reported by Blake (2008) who found that particle density of minerals in the sand and silt of soil were 2.65 Mg m^{-3} for quartz, 2.5 to 2.8 Mg m^{-3} for feldspars, 2.7 to 3.3 Mg m^{-3} for mica, and 3.1 to 3.3 Mg m^{-3} for apatite whereas density of clay minerals ranges between 2 to 3 Mg m^{-3} and that of humus is less than 1.5 Mg m^{-3}.

5.1.3 Porosity

Total porosity is the volume occupied by pores per unit volume of soil. It is considered as an index of relative pore volume in soil and is generally expressed in percentage whose values usually varies between 30% - 60% (ISSS, 2015). The porosity of forest soils usually ranges between 30% to 65% (Pritchett and Fisher, 1987). The soil porosity is determined by texture and arrangement of solid soil particles. In this study, the porosity of the AEU in post flood scenario ranged from 25.90% in Pananchery (Table 4.3) to 63.37% in Pazhayannur (Table 4.2) with an average value of 46.19%. Percentage distribution of soil samples based on porosity (%) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig.5.2.

Only 0.96% of the samples had a porosity less than 30%, 66.35% of them were in the range of 30- 50% and 32.69% of them had a porosity greater than 50%. Lower the porosity values, higher the compaction of soil which might have been due to higher bulk density because of washing away of organic matter content along with the floodwaters.

5.1.4 Maximum water holding capacity

The maximum water holding capacity (MWHC) of the AEU ranged from 29.28% in Puthur (Table 4.4) to 57.88% in Varantharappilly (Table 4.5) with a mean value of 43.89% (Table 4.4). The highest mean MWHC was observed in Varantharappilly panchayat (48.26%) and the lowest in Puthur panchayat (29.28%)(Table 4.10). Only one sample (0.96%) had a maximum water holding capacity of value less than 30%. It was also found that 83.65% had maximum water holding capacities ranging from 30- 50% and 15.38% of the samples had greater than 50%.

MWHC showed a significant and positive correlation with organic carbon. It is in conformity with the finding that soil organic matter stabilizes overall soil structure and thereby increases maximum water storage capacity of a soil and also the mean MWHC decreases with the increase in altitude (Bordoiloi *et al*., 2018). A similar trend was also observed in the study area where a lower MWHC was reported in Pazhayannur panchayath with highest altitude. Similar findings were also reported by Ramesh *et al*. (2009) and Debnath *et al* (2012). According to Debnath *et al*. (2012), organic carbon, sand, clay content and soil porosity were reported to be the key soil properties for predicting water holding capacity of soil. Percentage distribution of soil samples based on maximum water holding capacity (%) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig.5.3.

5.1.5 Moisture content

Soil moisture and soil temperature affects soil respiration (Tamai, 2010).The soil moisture content may increase up to 42% during the monsoons (Roxy *et al*., 2014). The soil moisture content of soils in the AEU 15 of Thrissur district ranged from 6.19% (Mattathur) (Table 4.6) to 59.44% (Varantharappilly) (Table 4.5)..The mean moisture content was highest in Pananchery panchayat (27.82%) and lowest in Mattathur panchayat (19.95%). About 1.92% of the soils in the study had a moisture content of less than 10% , 7.69 % of them were in the range of 10- 15%, 48.08 % of them were in the range of 15- 20% and 42.31% of them were greater than 25%. As per studies conducted in Arunachal Pradesh by Bordoiloi *et al*. (2018), the soil moisture content increases with the increase in altitude, while rainfall decreases with the increase in altitude which could be attributed to climatic, edaphic and vegetation condition. Venkatesh *et al*. (2011), in his study on different land covers on western ghats, concluded that soil moisture wasn’t solely influenced by land cover but also by other parameters.

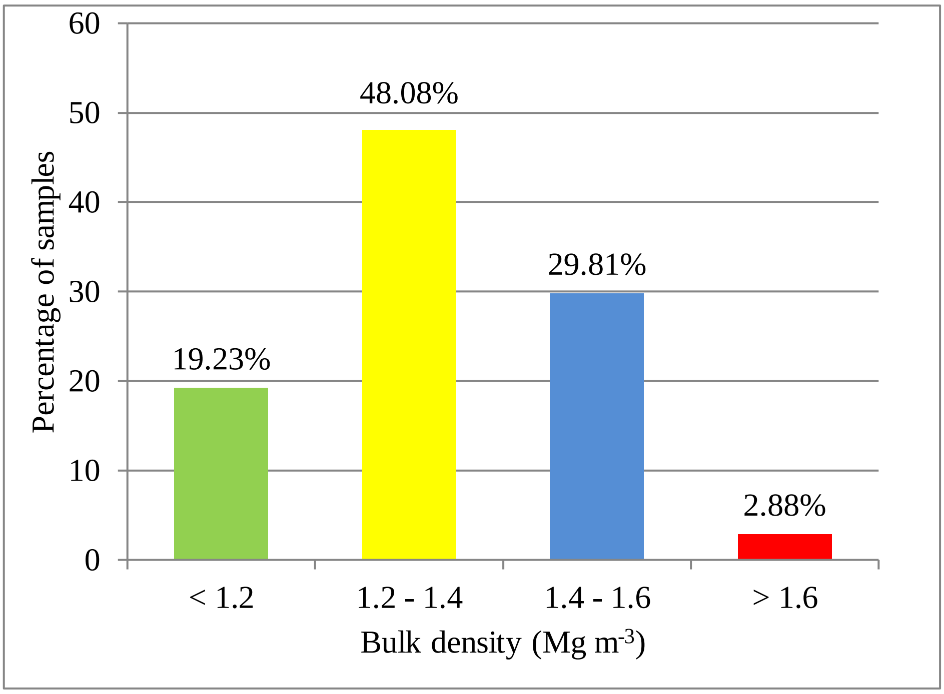


Fig.5.1 Percentage distribution of soil samples based on bulk density (Mg m^{-3}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

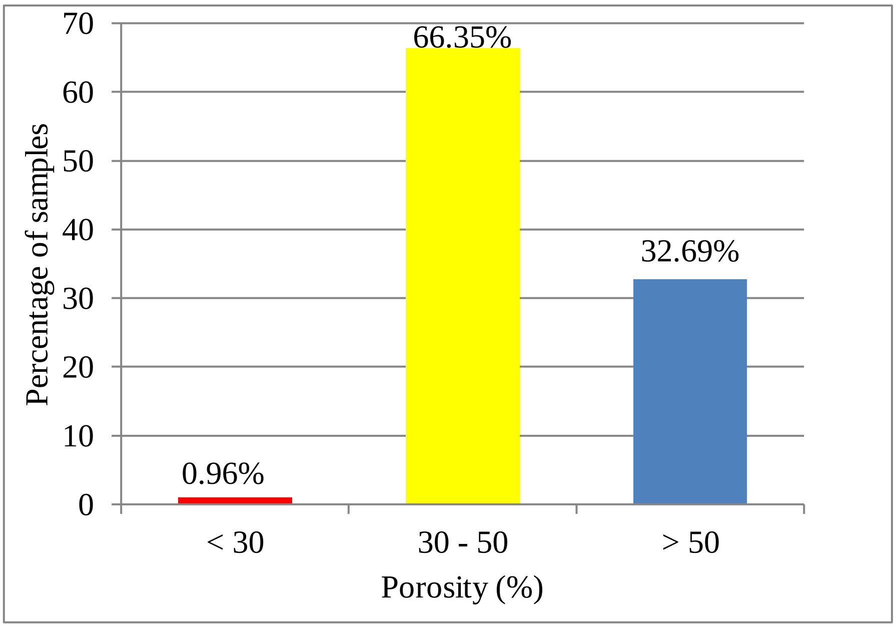


Fig.5.2 Percentage distribution of soil samples based on porosity (%) in the post-flood soils of AEU 15 in Thrissur district of Kerala

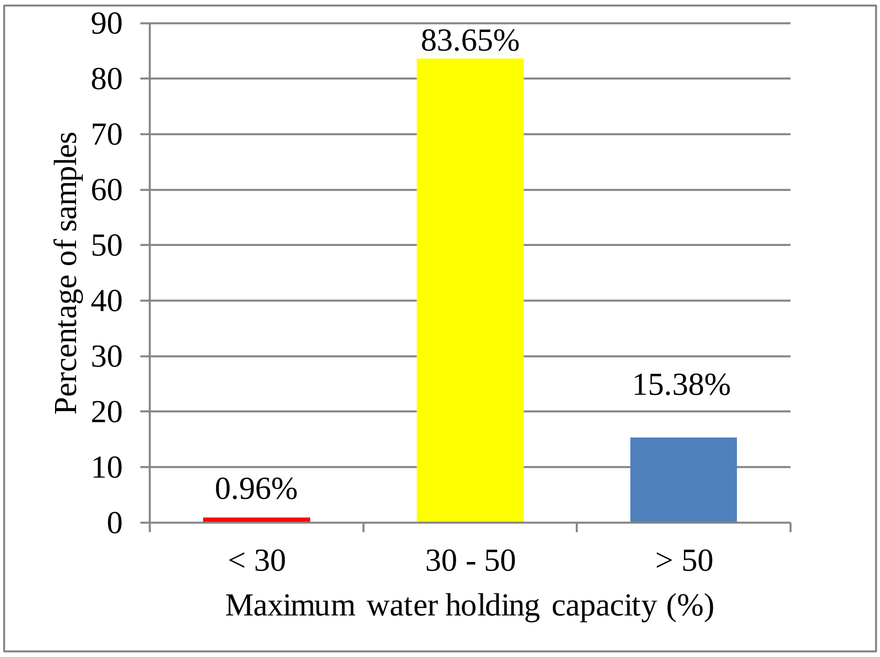


Fig.5.3 Percentage distribution of soil samples based on maximum water holding capacity (%) in the post-flood soils of AEU 15 in Thrissur district of Kerala

5.2 Chemical attributes of post flood soils of AEU 15

5.2.1 Soil reaction

The soils collected from all the panchayats after floods were all mostly acidic in nature. The pH values ranged from 4.48 in Pananchery (Table 4.13) to 6.75 in Mattathur (Table 4.16) with a mean value of 5.67. The highest mean pH was found in Mattathur panchayat (6.19) and the lowest mean pH in Pananchery (5.34) (Table 4.17).

About 14.42% of the soils had a pH less than 5 (very strongly acidic), 31.73% of them were in the range of pH 5.1- 5.5 (strongly acidic), 27.88% of them were in the range of pH 5.6 - 6 (moderately acidic), 17.31% were in the range of pH 6.1- 6.5 (slightly acidic) and a mere 8.65% of them were greater than a pH of 6.5 (neutral) (Appendix III). Percentage distribution of soil samples based on soil pH in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig 5.4.

The soil pH was found to be inherently acidic even before floods. This has been substantiated by studies of GoK (2013) (Appendix VI), Sujata *et al*. (2013), Bastin *et al*. (2014) and Shyju and Kumaraswamy (2019). It was found that the soil pH tended to be in the acidic range even after floods either due to inherent acidic pH, washing off of existing exchangeable bases from the soil or use of acidic fertilizers (Kumar *et al*., 2016). Recommended lime application based on soil pH have to be applied in acidic areas (Appendix IV).

5.2.2 Exchangeable acidity

The sum of exchangeable acidity and non-exchangeable acidity gives the total acidity. Exchangeable acidity is given by the Al^{3+} ion electrostatically retained on colloidal surfaces due to pH dependent negative charges (also known as exchangeable aluminum). The non-exchangeable acidity depends on the H covalently bound to polymers colloids and monomers of aluminum in soil (Raij *et al*., 2001; Hamilton *et al*, 2003).

Exchangeable acidity values of the AEU ranged from 0.80 in Pananchery (Table 4.13) and Varantharappilly (Table 4.15) to 2.50 cmol kg^{-1} (All panchayats) with a mean value of 1.80 cmol kg^{-1}. The highest mean value was observed in Pananchery panchayat (1.94 cmol kg^{-1}) and lowest in Pazhayannur panchayat (1.67 cmol kg^{-1}) About 18.27 % of them had an exchangeable acidity of less than 1 cmol kg^{-1}, 47.12 % of them ranged between 1- 2 cmol kg^{-1}, 34.62 % of them were greater than 2 cmol kg^{-1}.

5.2.3 Electrical conductivity

The electrical conductivity in the AEU ranged from 0.020 in Pananchery (Table 4.13) to 0.148 dS m^{-1} in Mattathur panchayat (Table 4.16) with a mean value of 0.051 dS m^{-1} . The highest mean value was observed in Pazhayannur (0.066 dS m^{-1}) and the lowest in Pananchery (0.031 dS m^{-1}) (Table 4.18). EC has a positive correlation with pH (r = 0.426^{**}) and a significant negative correlation (r = -0.199^{*}) with exchangeable acidity. All the samples (100%) had an electrical conductivity less than 1 dS m^{-1}.

Before the 2018 August floods, these panchayts in AEU 15 had EC values less than one, i.e, were non saline in nature (Kavitha, 2017 and Raghunath, 2017). No salinity was reported in any soils of the study area. Not much variation in the soils in EC was noted before and after the floods in the study area.

5.2.4 Organic carbon

In the current study, 39.4% of the soils had low (Appendix III). organic carbon content, 53.8 % of them had medium and 16.3% of the soils had a higher organic carbon content. The organic carbon content in post flood soils of AEU 15 ranged from 0.19 % in Pananchery (Table 4.13) to 2.24% in Pananchery (Table 4.13) with an average of 0.94%. The highest mean value was obtained from Varantharappilly panchayat (1.19%) and lowest from Puthur panchayat (0.77%) (Table 4.20). There was not much difference in organic carbon contents in the study area before (GoK, 2013) (Appendix VI); Kumar *et al*., 2016 and GoK, 2018) and after floods. The low to medium organic carbon content might have been due to erosion of topsoil during heavy rains in the high hills due to altitudinal differences and it might also be due to lesser accumulation of litter and low input of organic carbon in soils with increase in altitude and better stabilization of soil organic carbon at lower altitudes (Bangroo *et al.,* 2017)

Correlation analysis showed that organic carbon in soil has a positive and significant correlation with available nitrogen, available zinc, maximum water holding capacity, available magnesium, available copper and dehydrogenase activity. This correlation of organic carbon with aforesaid parameters indicates the importance of soil organic matter in enhancing the availability of nutrients like available N, Zn, Cu and Mg due to its chelating effect. Similar results were obtained by Shirgire *et al*., (2018). Its correlation with dehydrogenase activity were earlier reported by Mandal *et al*., (2007), Basak *et al.* (2013) and Brkljača *et al*. (2019). It also has a negative significant correlation with particle density.

As per reports from GoK (2018), Varanthirappilly and Puthur panchayats had high organic carbon whereas Pananchery, Mattathur and Pazhayannur possessed medium organic carbon before floods.

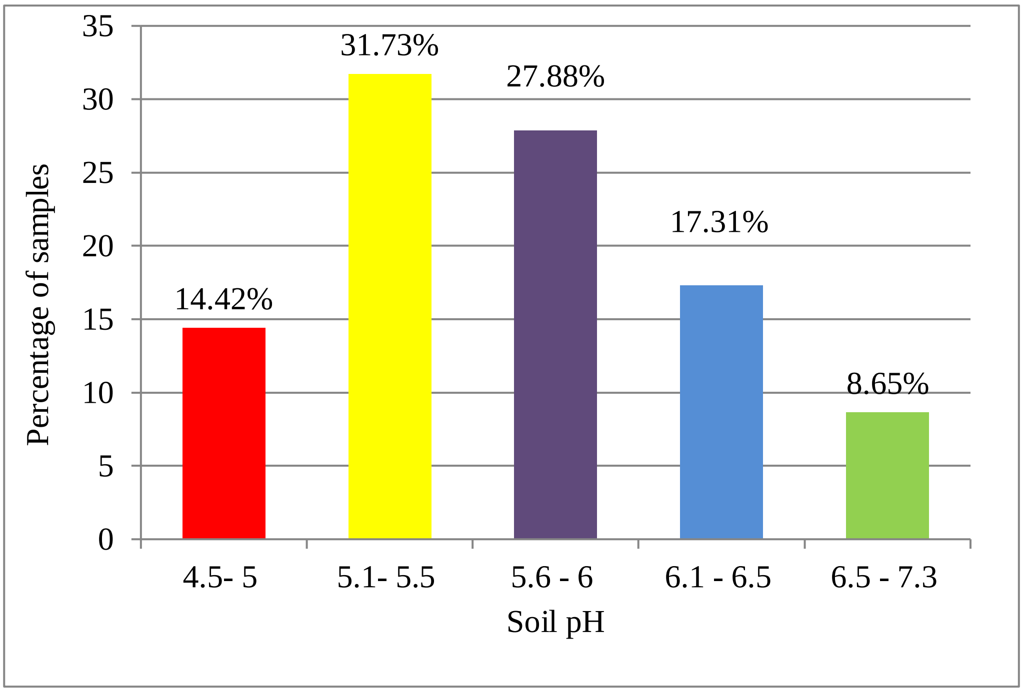


Fig.5.4 Percentage distribution of soil samples based on soil pH in the post-flood soils of AEU 15 in Thrissur district of Kerala

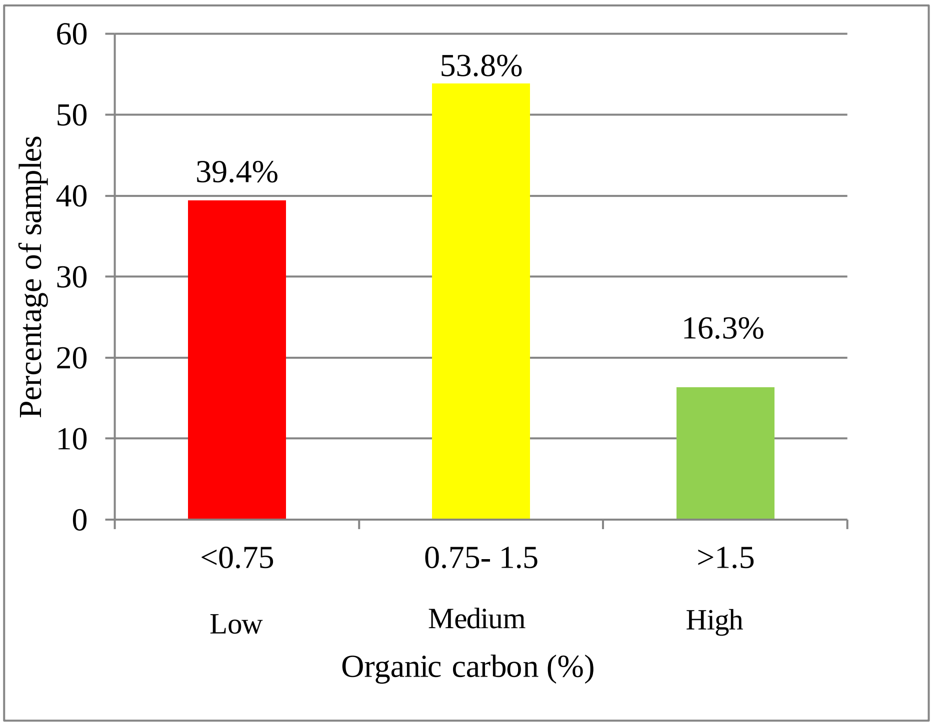


Fig.5.5 Percentage distribution of soil samples based on organic carbon (%) in the post-flood soils of AEU 15 in Thrissur district of Kerala

5.2.5 Available nitrogen

Nitrogen is considered as the most important nutrient for plant growth, yield, quality and the environment and is also a vital component of amio acids, auxins, cytokinins, alkaloids, glucosinolates, proteins and other components of food. The available nitrogen in soils in the study area ranged from 100.35 in Pananchery (Table 4.22) to 539.39 kg ha^{-1} in Pananchery (Table 4.22) with a mean of 172.36 kg ha^{-1}. The highest mean available nitrogen content was reported in Pananchery panchayat (181.05 kgha^{-1}) and lowest in Puthur panchayat (155.23 kg ha^{-1}) (Table 4.26).

Before August floods of 2018 (Appendix VI), there was adequate available nitrogen in the district (Sujata *et al.*, 2013 ; Bastin *et al.*, 2014). About 97.12% of the post flood soils had lower available nitrogen content (Appendix III), 2.88% of them were in the medium range and none of them fell under the high category. This might have been due to various losses including leaching losses as nitrate (Unger *et al*. 2009) and denitrification losses due to anaerobiosis during floods (Kalashetty *et al.*, 2012). Percentage distribution of soil samples based on available nitrogen (kg ha^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig. 5.6. Fertilizer recommendation based on soil test values have to be followed in nitrogen deficient areas (Appendix IV).

Correlation analysis shows that organic carbon and available nitrogen are significantly correlated ($r = 0.226^{*}$). This was in conformity with the studies of Cheng *et al*. (2016) and Brkljača *et al*. (2019).

5.2.6 Available phosphorus

Phosphorus is a key element in energy metabolism in basic biochemical processes such as photosynthesis and respiration and biosynthesis of nucleic acids and membranes. Prior to floods , the AEU 15 had high levels (Appendix VI) of available phosphorus (Sujata *et al.*, 2013; GoK, 2018). Available phosphorus contents of the post flood soils in AEU 15 of Thrissur district were all in the ‘high’ category (Appendix III). and it ranged ranged from 15.77 in Mattathur (Table 4.25) to 762.54 kg ha^{-1} in Varantharappilly panchayat (Table 4.24)with a mean value of 231.88 kg ha^{-1}. The highest mean available phosphorus was recorded in Varantharappilly panchayat

(419.41 kg ha^{-1}) and the lowest mean available phosphorus was recorded in Pananchery panchayat (86.1 kg ha^{-1}) (Table 4.27).

Significant differences in phosphorus contents before and after floods were not observed. This might have been due to continuous application of phosphatic fertilizers in the study area, dissolution of the applied phosphatic fertilizers stored in the soil during floods (Kalashetty *et al*., 2012) or by enhanced P release due to organic acids released from organic matter decomposition by the mechanism of reduction of metal ion bound phosphate in acidic soils via chelation or competition for exchange sites (Basak *et al*., 2016).

Correlation studies revealed that available phosphorus had a positive and significant relationship with available potassium, available sulphur and dehydrogenase activity. Similar results were reported by Parveen *et al.* (2018). The nutrient availability in flooded soils are governed by redox potential processes driven soil oxygen deficiency. With time, phosphorus became more available in flooded soils in some of the districts of the state after 2018 floods either from the reduction of iron or dissolution of calcium phosphates (KSDMA, 2018).

5.2.7 Available potassium

Potassium is considered one of the major nutrient elements in plants which is involved in opening and closing of stomata and nutrient uptake from soils. As per soil fertility data from GoK (2018), all the panchayats except Mattathur panchayat (medium) exhibited a high level of K content in their soils before floods . Available potassium content after the floods of 2018 in the AEU ranged from 53.20 in Pananchery (Table 4.22) to 648.59 kg ha^{-1} in Puthur (Table 4.23) with an average value of 241.34 kg ha^{-1}.

About 9.62% of the soils had low (Appendix III) available potassium content, 58.65% of them were in the medium range and 33% of them had a higher available potassium content indicating a fairly adequate level of available potassium in the soils. Percentage distribution of soil samples based on available potassium (kg ha^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig. 5.7.

After the floods, Pazhayannur , Pananchery and Mattathur exhibited medium K status in their soils. This decrease might have been due to erosion loss during heavy rainfall (Raghunath *et al.*, 2017) or due to heavy plant uptake and non replenishment through chemical fertilizers or not allowing the crop debris to decompose and release K to soils. Available potassium is lowest in Pazhayannur among all the panchayats because the panchayat is at a higher elevation than the others and it might have caused erosion and removal of available potassium in soils. Potassic fertilizers based on soil test values have to be applied as per recommendations based on soil test values (Appendix IV).

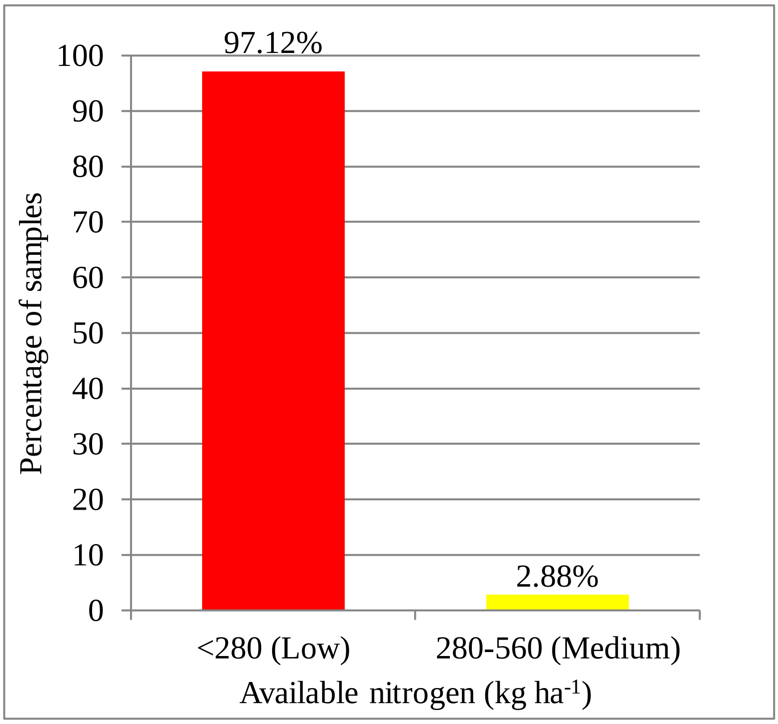


Fig. 5.6 Percentage distribution of soil samples based on available nitrogen (kg ha^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

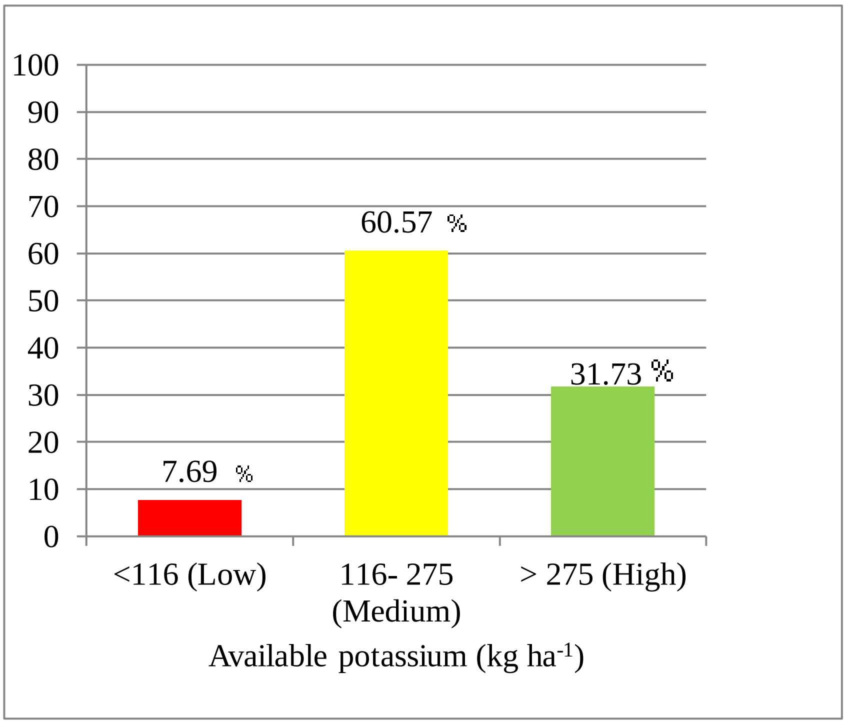


Fig. 5.7 Percentage distribution of soil samples based on available potassium (kg ha^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

5.2.8 Available calcium

As per a study conducted by Sujata *et al.* (2013), only 14 % of soils in AEU 15 were deficient in available calcium and about 86 % of the soils were adequate in available calcium content in their soils before 2018 floods. Studies by Kumar *et al.* (2016) also prove the same. Thrissur district was sufficient in terms of available calcium. As per GoK (2018) records, only Mattathur panchayat in AEU 15 in Thrissur district was deficient in terms of calcium. After the 2018 floods, about 99.04% of the post flood samples in the study area were sufficient (Appendix III) in available calcium and 0.96% were deficient. This is in conformity with the results of Kalashetty *et al.* (2012) where he noted that calcium content increased after the floods.

The available calcium content of the post flood soils ranged from 298.10 in Pazhayannur (Table 4.21) to 2118.00 mg kg^{-1} in Mattathur (Table 4.25) with a mean value of 740.68 mg kg^{-1}. The highest mean available calcium content was found in Mattathur. The content is highest in Mattathur panchayat among all the panchayats because this panchayat is at a lower elevation than the others and it might have caused deposition of calcium on the soil surface. Farmers were advised to apply lime consequent to increased acidity after the floods. This might have contributed to the increase in available calcium content after floods. Lime has to be applied as per recommendations based on soil test pH values in calcium deficient areas (Appendix IV).

5.2.9 Available magnesium

Government of Kerala (2018) reports support the deficiency of available magnesium in all the soils of AEU 15 in Thrissur district. As per research reports (Kavitha, 2019), northern high hills was found to contain low quantity of magnesium.

Kumar *et al.* (2016) reported that available Mg varied from 7 to 190.6 mg kg^{-1} with a mean of 49.7 mg kg^{-1} and it is found to be highly deficient in the district. The continuous application of concentrated primary fertilizer nutrients might have caused its deficiency in the district.

Percentage distribution of soil samples based on available magnesium (mg kg^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig.5.8. After floods, 59.62% of the samples were deficient (Appendix III) in available magnesium and 40.38% were sufficient. The available magnesium content ranged from 30.7 in Mattathur (Table 4.25) to 403.2 mg kg^{-1} in Pananchery (Table 4.22) with a mean value of 142.6 mg kg^{-1}. About 59.62% of the samples were deficient in available magnesium .

The deficiency may be attributed to the inherent acidic nature of soil (KAU, 2016), antagonistic action of available potassium in soils (Jayaganesh *et al*., 2011) or dissolution of these cations during floods and leaching away (Tsheboeng *et al*., 2014). There was a significant positive correlation of available magnesium with organic carbon . Similar results were obtained by Jayaganesh *et al*. (2011). This suggests that organic matter supplied available magnesium to the soils. Magnesium in the form of magnesium sulphate has to be applied to soil as per recommendations in magnesium deficient soils (Appendix IV).

5.2.10 Available sulphur

Prior to 2018 floods, sulphur was found to be deficient in all agroecosystems of AEU 15 in Thrissur district (Kavitha, 2019) and GoK (2018) reports claim that Pazhayannur, Puthur and Mattathur panchayats were deficient in sulphur. From post flood analysis, it was found that 58.65% of the soils were deficient in available sulphur content in the study area. This deficiency might have been due to the topography and soil characteristics such as coarse textured soils, lateritic and hill soils which were inherently found to be deficient in available sulphur (Biswas *et al*., 2014). Kavitha (2019) had attributed its deficiency to leaching of soluble sulphate salts during heavy rains. Percentage distribution of soil samples based on available sulphur (mg kg^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig. 5.9.

Available sulphur in soils ranged from from 0.40 in Pananchery (Table 4.22) to 55.09 mg kg^{-1} in Puthur (Table 4.23) with an average value of 6.46 mg kg^{-1}. The highest meant available sulphur was observed in Pazhayannur panchayat (12.9 mg kg^{-1}) and lowest mean in Mattathur panchayat (1.29 mg kg^{-1}) (Table 4.31). With respect to available sulphur, almost all parts of Thrissur district, the concentration was higher than the critical limit. The mean value was three times of the critical limit and is equal to 15 mg kg^{-1}. Here, available sulphur showed correlation with soil pH (Kumar *et al.,* 2016)**.** Sulphate fertilizers based on soil test values have to be applied as per recommendations based on soil test values (Appendix III).

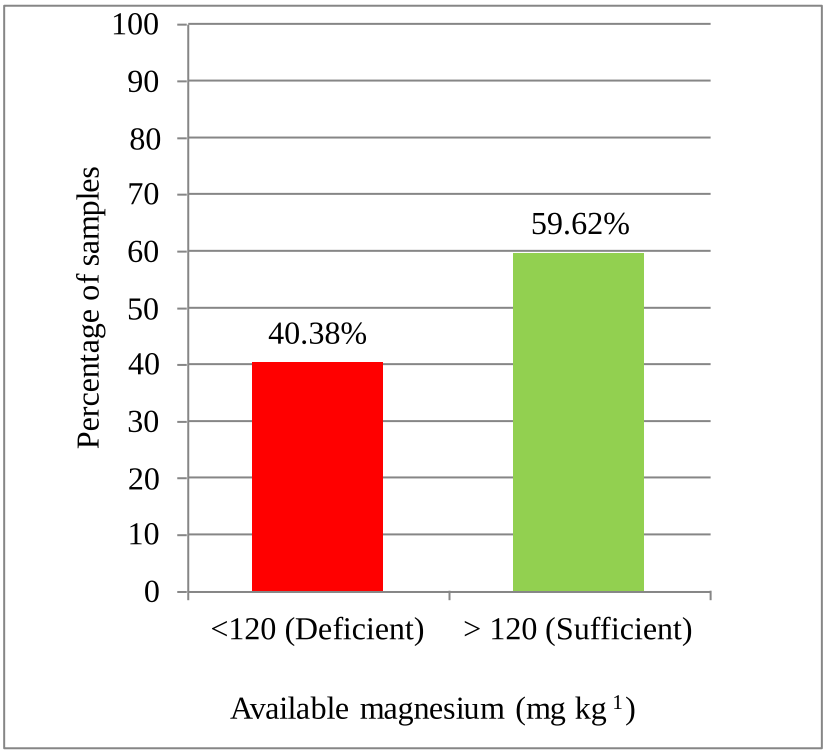


Fig.5.8 Percentage distribution of soil samples based on available magnesium (mg kg^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

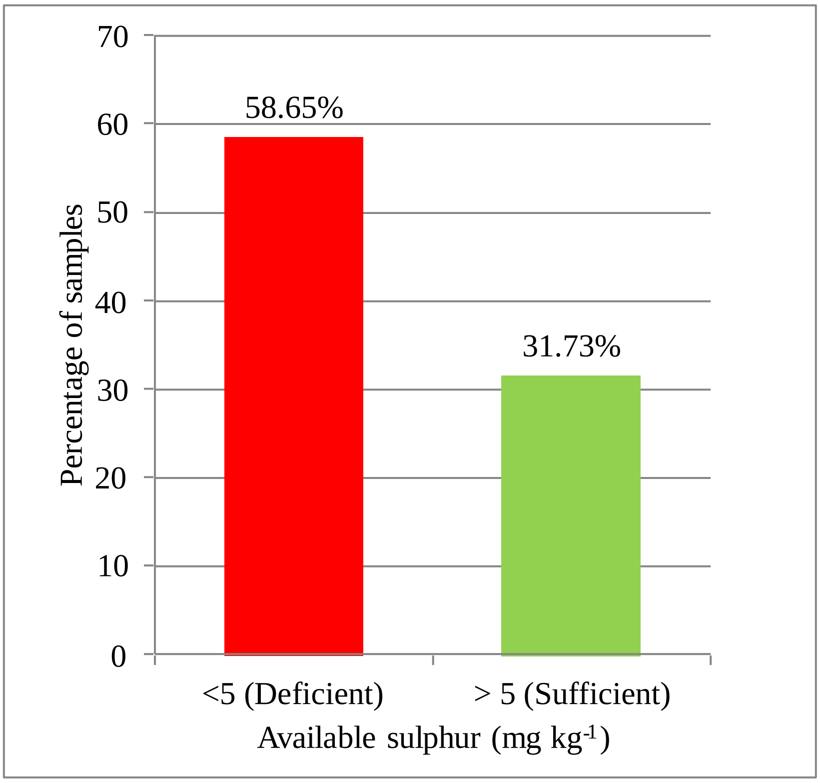


Fig. 5.9 Percentage distribution of soil samples based on available sulphur (mg kg^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

5.2.11 Available iron

In general , Kerala soils possess high (Appendix III) levels of available iron in their soils (KAU, 2016). Similar observations were made by Bastin *et al*. (2014) and Kumar *et al*. (2016). This study shows that all panchayats in the study area were found to be sufficient in available iron content in their soils even after floods. The available iron ranged from 15.43 mg kg^{-1} (Pananchery) to 239.40 mg kg^{-1} (Pananchery) with a mean value of 72.10 mg kg^{-1}. The highest mean available iron was observed in Pazhayannur panchayat (91.20 mg kg^{-1}) and the lowest in Varantharappilly panchayat (58.66 mg kg^{-1}) (Table 4.42).

These high levels of iron might have been due to tropical lateritic nature of the study area (Raymahashay *et al*., 1985; Chandran *et al*. 2005; Mielki *et al*., 2016). Available iron exhibited a positive and significant correlation with available copper and available manganese and a negative correlation with available potassium.

5.2.12 Available manganese

Raghunath (2017) recorded very high manganese content well above the critical range in Potta region in Pazhayannur panchayat before 2018 floods. Kavitha *et al*. (2019) also similarly observed a similar trend that a very high level of available manganese was present in 93.98% of Thrissur district which was also substantiated by KAU (2016). Even after floods, it was observed that all the panchayats in the study area were sufficient in available manganese content in their soils.

The available manganese content ranged from 6.04 mg kg^{-1}Pananchery (Table 4.33) to 117.00 mg kg^{-1} in Pananchery (Table 4.33) with an average of 37.20 mg kg^{-1}. The highest mean value was observed in Pazhayannur (70.20 mg kg^{-1}) and the lowest in Mattathur panchayat (23.52 mg kg^{-1}) (Table 4.43).These high levels of manganese or rather its toxicity is attributed to highly acidic soils (pH below 5.5) where parent materials are rich in total manganese (Unni *et al*., 1995; Behera *et al*., 2014) or they may also occur due to chelation of manganese with organic compounds released during organic matter decomposition (Raghunath, 2017) . Alfredo *et al*. (2009)

reported that during submergence , the concentrations of total soluble manganese increased. iron and manganese oxides are also reported to fix other micronutrients such as cobalt, copper, zinc , nickel and lead, making it unavailable to plants (Unni *et al*., 1997). Both iron and manganese toxicities can be managed by application of lime in soils (KAU,2016).

5.2.13 Available copper

Prior to 2018 floods, 90 per cent of the soils of AEU 15 had sufficient (Appendix III) levels of available copper and 10% of the soils were deficient in copper (Sujata *et al.*, 2013) and Kavitha *et al*. (2015) reported that 85.2% of Thrissur were found to contain high levels of copper.

Copper was found to be sufficient in all panchayats under study (GoK, 2018) (Appendix VI). Even after floods, the panchayats under study were sufficient in terms of available copper content in their soils. The available copper contents ranged from 0.84 in Pananchery to 16.37 mg kg^{-1} in Pananchery (Table 4.33) with a mean of 4.40 mg kg^{-1}. Puthur panchayat exhibited the highest mean available copper content (5.95 mg kg^{-1}) and Mattathur panchayat exhibited the lowest mean (2.55 mg kg^{-1}) (Table 4.44). The high incidences of copper in soils might have been due to prevalent use of copper containing pesticides in the area (Shakhila and Keshav, 2014). Brady and Weilm (2002) and Sathish *et al*. (2018) reported that the solubility, availability and uptake of copper is higher under acidic conditions (pH of 5.0 to 6.5).

5.2.14 Available zinc

Kumar *et al*. (2016) and GoK (2018) recorded available zinc in the sufficiency (Appendix III) range in Thrissur district before floods. Sufficient available zinc was present in all the panchayats under study even after floods. No deficiencies were noted in any of the panchayats. The available zinc content in soils ranged from from 1.22 mg kg^{-1} in Pananchery (Table 4.33) to 21.57 mg kg^{-1} in Mattathur (Table 4.36) with a mean value of 4.31 mg kg^{-1}. The lowest mean available zinc content was obtained in Varantharappilly (3.66 mg kg^{-1}) and highest in Puthur panchayat (5.23 mg kg^{-1}) (Table 4.45).

Available zinc exhibited positive correlation with pH, exchangeable acidity, electrical conductivity, organic carbon, available manganese, copper and dehydrogenase activity (Rajeswar *et al*., 2009 ; Ghode *et al*., 2020). Sufficiency status of zinc in Thrissur district might be due to its presence as a contaminant in phosphatic fertilizers which is applied luxuriously in the area (Kavitha and Sujatha , 2015) or might be due to acidic condition of soils (Sheeja, 1994).

5.2.15 Available boron

As per KAU (2016) and GoK, (2018), soils in the study area were deficient (Appendix III) in boron prior to floods. According to the post flood study, all the panchayats were deficient in terms of available boron content with boron content ranging from 0.003 mg kg^{-1} in Pazhayannur (Table 4.32) to 0.298 mg kg^{-1} Puthur (Table 4.34) with a mean of 0.030 mg kg^{-1}. The highest mean available boron was in Puthur panchayat (0.049 mg kg^{-1}) and the lowest mean in Pazhayannur panchayat (0.003 mg kg^{-1}) (Table 4.46).

Such deficiency of boron is commonly observed in soils containing a high amount of calcium carbonate or oxides and hydroxides of iron and aluminium and also in soils of low organic matter content (Sheeja, 1994). The deficiency might also be caused by leaching loss (because of high precipitation) and fixation of the element in unavailable forms or low EC in soils (Mishra, 1981). Availability of boron is greatly governed by pH, but here no such correlation with pH was observed in the study area which indicate that pH was not only the parameter that governed its availability in soil.

5.3 Biological attribute of post flood soils under AEU 15 in Thrissur district

Dehydrogenase activity

Dehydrogenase enzyme play an important role in the bio oxidation of soil organic matter by transferring hydrogen from organic substrates to inorganic acceptors (Zhang *et al*., 2010). The range of dehydrogenase activity in post flood soils was from 0.23 in Pananchery (Table 4.37) to 477.37 µg TPF g^{-1} 24 hr^{-1} in Mattathur (Table 4.41) with a mean value of 120.29 µg TPF g^{-1} 24 hr^{-1}. This wide variation in dehydrogenase enzyme activity might be due to proximity of sampling sites to river banks with a higher moisture content and the prevalence of obligate anaerobes therein which are responsible for a varied dehydrogenase activity (Wolińska and Stępniewska, 2012). The highest mean value was observed in Pazhayannur panchayat (477.37 µg TPF g^{-1} 24 hr^{-1}) and lowest mean in Pananchery panchayat (60.43 µg TPF g^{-1} 24 hr^{-1}) (Table 4.47). Here, dehydrogenase activity showed a significant and positive correlation with organic carbon which is in agreement with the observations of Brkljača *et al*. (2019).

Percentage distribution of soil samples based on dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig. 5.10. About 44% of the samples had a dehydrogenase activity less than 75 µg TPF g^{-1} 24 hr^{-1}**,** 22% of them were in the range of 75- 150 µg TPF g^{-1} 24 hr^{-1}, 23% were in the range of 150- 225 µg TPF g^{-1} 24 hr^{-1} and only 15% of them had a dehydrogenase activity greater than 225 µg TPF g^{-1} 24 hr^{-1}. Flooded conditions induced higher DHA in soils. This is in conformity with the studies of Trevors (1984), Subhani (2001) and Beena *et al*. (2017).

5.4 Soil quality index and Relative soil quality index

The soil quality index values ranged from 0.33(Pananchery) to 0.71 (Pananchery). The highest mean SQI was observed in Varantharappilly (0.57) and lowest mean in Pazhayannur (0.52). Since SQI is a summation of products of scores and weightage factor, higher the weightage factor and the score value, higher will be the SQI. In this study, weightage factors for MDS parameters were in the following decreasing order (Table. 4.48) : pH > available magnesium> porosity> available manganese > available potassium= MWHC > available nitrogen >available boron. Higher the score values, higher would be its contribution to the SQI.

Highest RSQI value was observed in Pananchery panchayat (78.13%) and also the lowest in the same panchayat (35.65%). The highest mean RSQI was recorded in Varantharappilly panchayat (61.81%) and lowest in Pananchery panchayat (48.17%). Percentage distribution of Relative soil quality index in the post-flood soils of AEU 15 in Thrissur district of Kerala is given in Fig. 5.11. About 11.53% of the samples were rated as belonging to the 'poor' category (RSQI <50%), 81.73% of the samples as 'medium' (RSQI = 51-75%) and 6.73% of the soil samples as 'good'(RSQI > 75%) (Appendix III).

5.5 Nutrient index

Nutrient indices of flood affected areas in the AEU 15 in Thrissur district were low (NI<1.67) with respect to available nitrogen, medium (1.67- 2.33) with respect to organic carbon and available potassium whereas nutrient index was high (NI>2.33) with respect to available phosphorus. A low nutrient index means that a higher number of samples fall under the lower category. Nutrient index for available nitrogen was low due to higher number of samples (97.12 %) falling in the lower category (<280 kg N ha^{-1}). In case of available phosphorus, the flood affected soils had high nutrient index due to a higher number of samples (100%) in the higher category (>25 kg ha^{-1}) (Appendix III).

A medium nutrient index, in case of available potassium and organic carbon was due to higher number of samples falling under the medium category.

When different panchayats of the AEU were compared, nutrient index for organic carbon was rated low (NI <1.67) for Pananchery, Puthur and Mattathur and medium for Pazhayannur and Varantharappilly panchayats. All the panchayats showed a low nutrient index (NI <1.67) for available nitrogen because a higher number of samples had a low availabale nitrogen content in all the panchayats. In case of available phosphorus, all the panchayat showed a remarkable high nutrient index (NI >2.33) with the highest NI in Pazhayanur, Puthur and Varathirappilly panchayat (NI = 3) and lowest in Pananchery (NI = 2.5). Nutrient index for available potassium was high (NI > 2.33) for Puthur (NI=2.5) and Varantharappilly (NI=2.45) panchayat whereas it was medium for Pazhayannur (NI=2.2), Pananchery (NI=1.97) and Mattathur (NI=2.19).

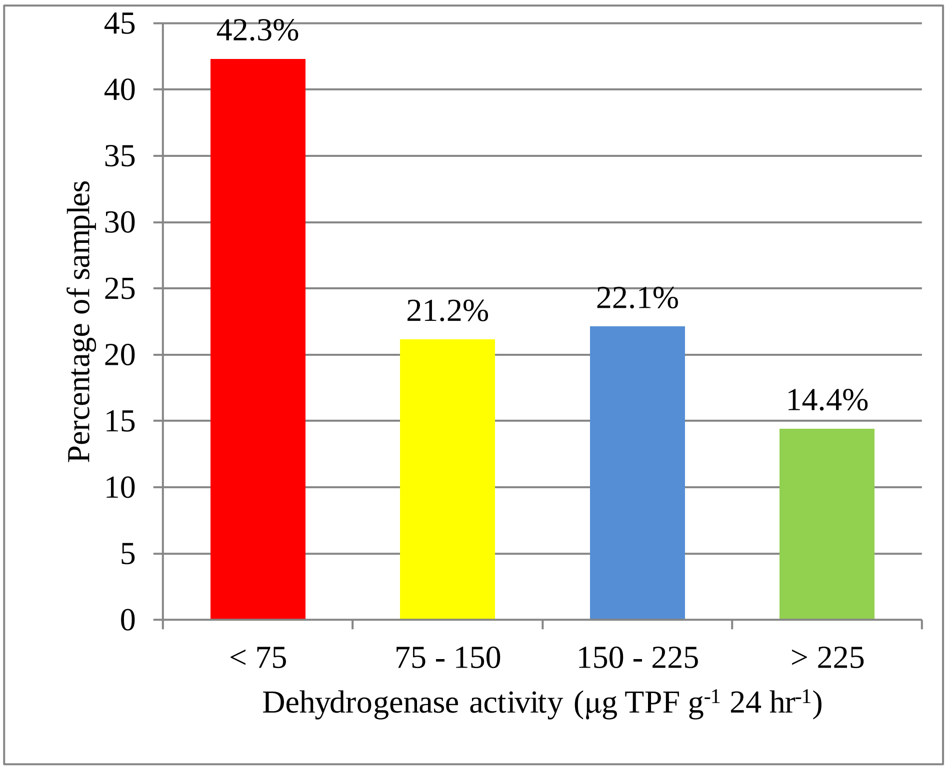


Fig. 5.10 Percentage distribution of soil samples based on dehydrogenase activity (µg TPF g^{-1} 24 hr^{-1}) in the post-flood soils of AEU 15 in Thrissur district of Kerala

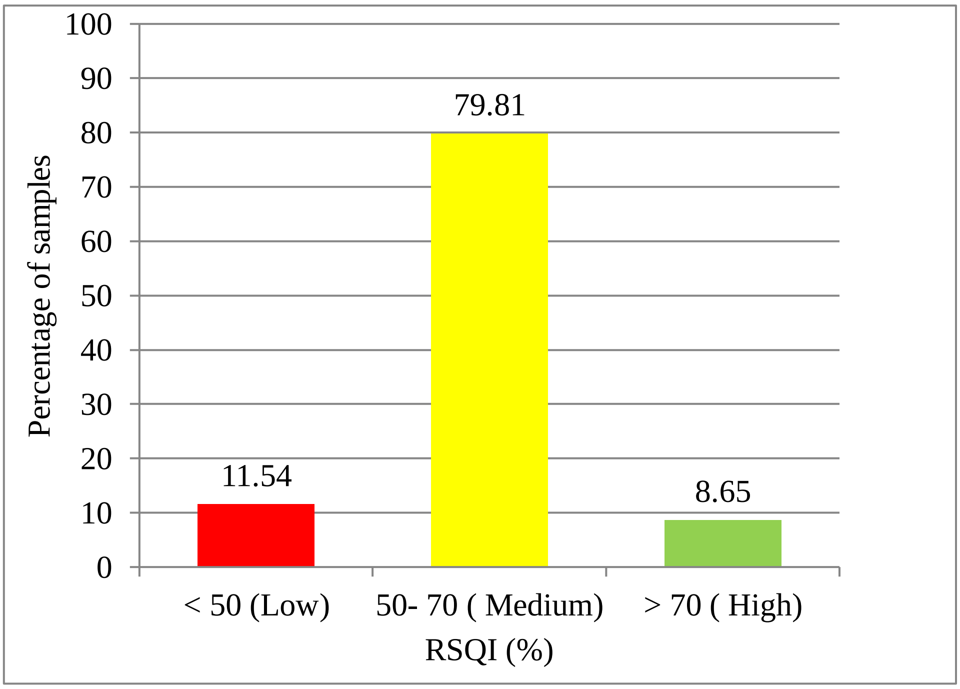


Fig. 5.11 Percentage distribution of Relative soil quality index in the post-flood soils of AEU 15 in Thrissur district of Kerala

SUMMARY

6. SUMMARY

The devastating flood of 2018 in Kerala had caused great damage to life and property. The state had witnessed a heavy rainfall of 2346.3 mm from 1 June to 31 August, as against the normal value of 1649.5 mm. which was 42 per cent more than the usual rainfall. This had led to the opening of 39 dams in the state when water level rose well above their bearing capacity which was a critical moment in the history of the state. Opening of dams further aggravated the problem by causing overflow of rivers and changing the course of the rivers. This phenomenon lead to soil erosion and landslides in hilly areas and waterlogged conditions in low lying areas. Various depositions of mud, debris and organic matter and also their removal were noticed in several areas of the state. As far as agriculture is concerned, floods had changed the structural, textural, chemical and biological aspects of soil or has caused a change in the soil quality. Soil quality determines the agricultural productivity of an area and as such, is important for post flood soil quality assessment studies.

This study entitled 'Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques' was therefore conducted with an objective to assess their soil quality and prepare maps using GIS. The current study was conducted in five panchayats namely Pazhayannur, Pananchery, Puthur, Varantharappilly and Mattathur which come under AEU 15 of Thrissur district. A total of one hundred and four geo-referenced soil samples were collected from these panchayats. The soil samples were assessed for physical parameters like bulk density, particle density, porosity, water holding capacity, moisture content. Chemical parameters included in the study were pH, electrical conductivity, exchangeable acidity, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper and boron. Dehydrogenase activity was the biological soil quality parameter analysed in the study.

A minimum data set (MDS) was developed using principal component analysis (PCA). Seven principal components (PC) with eigen values greater than one were extracted using PCA. The soil parameters with highest loading factor value in a PC group was retained in the group. When there were more than one parameter in a

PC group (Here PC 5), the correlation of the parameters was found out. Least correlated parameters (r<0.6) were retained in the PC group. the parameter with highest factor loading was retained when the parameters were highly correlated (r>0.6). Finally, a Minimum Data Set (MDS) comprising of eight soil parameters were formed comprising of porosity, maximum water holding capacity, available, , nitrogen, potassium, magnesium and boron, as 'more is better' functions; pH as 'optimum' function and available manganese as 'less is better' function. Indicators were scored based on whether they belonged to 'more is better', 'optimum' or 'less is better' functions using non linear scoring method. Weightage factor for each indicator was developed using ratio of variance of the principal component (to which the indicator belonged) to the total variance. The products of score and weightage factor of each site were finally summed up to obtain soil quality index of that particular site. Relative soil quality and nutrient indices (NI) were also calculated. The salient findings of the study are given below:

Plantation crops grown in the AEU were coconut , arecanut and rubber. Spice crops like pepper, nutmeg, turmeric and ginger, and vegetables like bittergourd, cowpea, ashgourd, coleus, bottlegourd and coccinia sp were cultivated. Banana was also grown by farmers of the AEU. Arecanut – coconut based homestead agriculture was followed in the area.

The bulk density values ranged from 0.83 to 1.74 Mg m^{-3} and 80.77% of the soils had a bulk density greater than 1.20 Mg m^{-3}. Porosity ranged between 30 and 60% in 99.04 per cent of the samples and 83.65 per cent of the samples had maximum water holding capacity between 30 and 50 %.

In terms of soil reaction, it was observed that 8.65 per cent of soils expressed neutral pH and 91.35 per cent of the soils remained acidic (pH 4.40- 6.50).

All the samples had an electrical conductivity less than 1 dS m^{-1} and were non saline. In case of exchangeable acidity, 81.74 per cent of the samples had values greater than 1 cmol kg^{-1} .

The organic carbon content in post flood soils of AEU 15 ranged from 0.19 to 2.20 per cent; 39.40 per cent of the samples had low and 53.80 per cent had medium organic carbon content.

There was no significant difference in available nitrogen content between the panchayats and 97.12 per cent of the soils had a lower available nitrogen content (< 280 kg ha^{-1}). In case of available potassium, 58.65 per cent of the samples had medium and 31.73 per cent had high content. Available potassium content of the AEU ranged from 53.20 to 648.59 kg $ha^{-1}$with an average value of 241.34 kg ha^{-1}. All the samples were rated high (>25 kg ha^{-1}) in available phosphorus content.

Available calcium content was sufficient (>300 mg kg^{-1}) in 99.04 per cent of the samples. Deficiency of available magnesium (<120 mg kg^{-1}) was found in 59.62 per cent of the samples. More than fifty per cent of samples (58.65%) were deficient in available sulphur.

All the samples were sufficient in available iron, manganese, copper and zinc. There was no significant difference in available boron content between different panchayats. All the samples were deficient (<0.5 mg kg^{-1}) in available boron and boron content ranged from 0.003 to 0.298 mg kg^{-1}.

Dehydrogenase activity of the flood affected soils ranged from 0.23 to 477.37 µg TPF g^{-1} 24 hr^{-1}.

Nutrient indices of flood affected areas in AEU 15 in Thrissur district were low (NI <1.67) with respect to available nitrogen, medium (NI=1.67 to 2.33) with respect to organic carbon and available potassium and high (NI >2.33) for available phosphorus.

The highest mean soil quality index of 0.57 was observed in Varantharappilly panchayat whereas the lowest mean SQI of 0.52 was reported in Pazhayannur panchayat relative soil quality index (RSQI) was medium in 79.81 per cent of the soils in AEU 15.

Organic carbon showed a significant positive correlation with maximum water holding capacity, available nitrogen, magnesium, zinc, copper and dehydrogenase activity.

In comparison with preflood data (GoK, 2013), the post flood soils were acidic (pH 4.40- 6.5) except 8.65 per cent of the samples falling in the neutral range (6.60 - 7.30). Application of lime due to increased acidity after the floods in the area as recommended to farmers soon after the floods might have contributed to the increase in content of available calcium after floods.

While comparing pre and post flood situations of organic carbon content in the soil, there was a shift to low and medium categories of the nutrient indicating a loss of organic matter from the soils.

Available nitrogen content was low when compared to preflood soils of the area. But there was an increase in the content of available phosphorus, potassium, calcium, magnesium, copper and zinc contents in soils after floods in the AEU.

Available sulphur and boron in post flood soils became more deficient after the floods (GoK, 2013).

In brief, increase in bulk density was noticed in the soils after floods. A small percentage of soils with neutral pH was also observed, while the majority of soils remained acidic. All the soils were non saline. Significant losses of organic carbon, available nitrogen, sulphur and boron were noticed in flood affected soils of AEU 15.

Future line of work

i. The impacts of soil crusting, a common phenomenon observed after the floods, on soil physical, chemical and biological properties need to be studied in detail.

ii. Changes in beneficial microflora in the soils after floods may be investigated and appropriate biofertilizers may be recommended for a particular site
iii. Soil quality based database for each cropping system in AEU may be developed and compared.
iv. AEU-based cropping and fertilizer recommendations may be developed and recommended.
v. Climate resilient sustainable agriculture may be adopted in flood prone areas of the state.

REFERENCES

References

Acton, D.F. and Gregorich, L.J., (eds). 1995. *The Health Of Our Soils:Towards sustainable agriculture in Canada*. Ottawa, Agriculture and Agri-Food Canada. 138p .

Akpoveta, O., Steven, A., Osakwe, Osaro, K. Ize-Iyamu, Weltime, O., Medjor, Egharevba**,** F**.** 2014. Post flooding effect on soil quality in Nigeria: the Asaba, Onitsha experience. *Open J. Soil. Sci*. 4(2): 72-80.

Alfredo, B., De-Campos, Amrakh, I., Mamedov and Huang, C. 2009. Short-term reducing conditions decrease soil aggregation . *Soil Sci. Soc. Am J*: 73(2) 550-559.

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

Askari, M and Holden, N. 2015. Quantitative soil quality indexing of temperate arable management systems. *Soil and Tillage Res*. 150: 57-67.

Avnimelech, Y., Ritvo, G., Leon, E., Meijer, and Kochba, M. Y. 2001. Water content, organic carbon and dry bulk density in flooded sediments. *Aquac Eng*. pp 25–33.

Bangrooa, S.A.,. Najara , G.R Rasoolb, A. 2017. Effect of altitude and aspect on soil organic carbon and nitrogen stocks in the Himalayan Mawer Forest Range. *Catena* 158 : 63–68.

Basak, N., Datta, A., Biswas, S., Mitran,T., and Mandal, B. 2016. Organic amendment influences soil quality in farmers' field under rice-based cropping systems in Indo-Gangetic plains of India . *J. Indian Soc. Soil Sci*. 64 (2): 138-147.

Bastin, B., Beena, V. I., Sreelatha, A. K., and Dey, P. 2014. *GPS And GIS Based Model Soil Fertility Maps For Precise Fertilizer Recommendations to the farmers of Kerala.* Kerala Agricultural University, Thrissur. 161p.

Behera, S. K and Shukla, A. K. 2014. Total and extractable manganese and iron in some cultivated acid soils of India: status, distribution and relationship with some soil properties. *Pedosphere.* 24(2):196–208. doi:10.1016/s1002-0160(14)60006-0

Biswas, B. C. and Sarkar, M.C., Tanwar, S., S. Das, and Kalwe, S.P. 2004. Sulphur deficiency in soils and crop response to fertilizer sulphur in India. *Fertilizer News*. 49 (13): 18-21.

Blake, G. R. 2008. Particle density. In: Chesworth W. (eds). Encyclopedia of Soil Science. Encyclopedia of Earth Sciences Series. Springer, Dordrecht.

Bordoloi, Ritashree, Das, Biswajit , Yam, Gyati, Pandey, Pankaj and Tripathi. 2018. Modeling of water holding capacity using readily available soil characteristics. *Agric. Res* .

Brady, N.C. and Weilm, R. 2002. *The Nature and Properties of Soils*. (13th ed). Prentice Hall Inc., New Jersey, USA, 960p.

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

Brkljaca, M., Kulisic, K. and Andersen, B. 2019. Soil dehydrogenase activity and organic carbon as affected by management system. *Agric. conspec. sci.* 84.(2): 135-142.

Brzezinska, M., Stepniewski, W., Stepniewska, Z., and Przywara, G. 2001. Effect of oxygen deficiency on soil dehydrogenase activity in a pot experiment with Triticale cv. Jago vegetation. *Int. Agrophysics*, 15: 145-149.

Chandran P., Ray, S. K., Bhattacharya, T., Srivastava, P., Krishnan, P., and Pal, D. K. 2005. Lateritic soils of Kerala, India: their mineralogy, genesis, and taxonomy. *Aust. J. Soil Res.* 43: 839-852.

Chaudhari, P. R., Ahire, D. V., Ahire, V. D., Chakravarty, M., and Maity, S. 2013. Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *Int. J. Sci. Res*. 3(2) : 2250-3153.

Cheng W., Padre A. T., Sato C., Shiono H., Hattori S., Kajihara A., and Kumagai K. 2016. Changes in the soil C and N contents, C decomposition and N mineralization potentials in a rice paddy after long-term application of inorganic fertilizers and organic matter. *Soil Sci Plant Nut* 62(2): 212–219.

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

Debnath, P., Sen, D., Pattanaik, S.K., Sah, D., Ghosh, S. K. 2012. Physico-chemical properties and its relationship with water holding capacity of cultivated soils along altitudinal gradient in Sikkim. *Int. J. Agric. Environ. Biotechnol.*5 (1): 99–102.

Doran, J.W. and Parkin, T.B .1994. Defining and Assessing Soil Quality. In : Doran, J.W., Coleman, D.C., Bezdicek, D.F. and Stewart, B.A. (eds). *Defining Soil Quality for a Sustainable Environment*, Soil Science Society of America, Madison, 35: 3-21.

DSSC [Department of Soil Survey and Conservation]. 2018. Soil health status in Kerala in post flood scenario. Department of Soil Survey and Conservation, Thirunvanathapuram. 344p.

George, B. S., Ashique, T.K., and Binitha, N. K. 2017. Assessment of microbial properties of pokkali soil in Kerala, India. *Int. J. Curr. Microbiol. App. Sci* . 6(12): 1964-1967.

Ghode, M. K., Vaidya, P. H., Nawkhare A.D., and Ingole, A. J. 2020. Relationship between soil physico-chemical properties, available macro and micronutrients and yield in cotton growing soils of Nanded district of Maharashtra. *J. Pharmacognosy Phytochem*. 9(3): 2062-2065**.**

GOK [Government of Kerala]. 2013. *Kerala Soil Health Information System* [on-line] Available. http://www.keralasoilfertility.net/pdf [25 August 2020].

Guppy, C., Moody, P., and Tighe, M .2018. Reserve phosphorus (P) and potassium (K) availability and release in northern region soils; effects of flooding and fertiliser bands. Grains Research and Development Corporation. Available: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/07/reserve-p-and-k-availability-and-release-in-northern-region-soils

Hamilton, A., Muraoka, T., and Lavorante, A. F. 2013. Relationship between acidity and chemical properties of Brazilian soils. *Scientia Agricola*. 60 (2): 337-343.

Hao, X., Ball, B.C., Culley, J. L. B., Carter, M. R., and Parkin, G. W. 2008. Soil Density And Porosity. In: Carter, M. R. and Gregorich, E. G. (eds.), *Soil Sampling and Methods of Analysis*. Canadian Society of Soil Science, Boca Raton, USA, pp. 743 - 759.

Hatai, L. D., Sen, C., Singh, H. P., and Naik, D. 2010. Problems and Prospects of Pineapple Marketing in West Garo Hills of Meghalaya-An Economic Evaluation. *Indian J. Agric. Econ.* 65 (3): 38.

Hoffman, K. and Kunze, R. 1971. Characteristic Values. In: *Linear Algebra*. [2nd Ed], Englewood Cliffs, New Jersey, Prentice Hall, 182p.

ICAR-CPCRI. 2019. Annual report 2018-19. ICAR- Central Plantation Crops Research Institute, Kasargod, Kerala, India, 164p.

Inglett, P., Reddy, K. and Corstanje, R. 2005. Anaerobic soils. In: Encyclopedia of Soils in the Environment. Elsevier, Amsterdam, pp. 72-78.

Irfan M., Hayat S., Hayat Q., Afroz S., and Ahmad A. 2010. Physiological and biochemical changes in plants under waterlogging. *Protoplasma* 241: 3–17.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi. 498p.

Jayaganesh, S., Venkatesan, S., Senthurpandian, V. K., and Poobathiraj, K. 2011. Vertical distribution of magnesium in the laterite soils of south India. *Int. J. Soil Sci.* 6: 69-76.

Joy, P. 2020. Challenges of climate change on spice crops in Kerala. *Int J. Herbal Medicine* 8(3): 17-19.

Kalamkar, S.S. 2008. Agriculture Development in North-Eastern Region of India. In: K.K. Bagchi (Eds) Agricultural Development in North-East India: Issue and Options, Abhijeet Publications, Delhi, pp. 42-71 (ISBN: 978-81-89886-44-8).

Kalashetty, B.M., Giraddi, T.P., Kalshetti, M.B., and Sheth, R.C. 2012. River Krishna flood effects on soil properties of cultivated areas in Bagalkot district, Karnataka state. *Global J. Sci. Frontier Res. Chem*. 12(6): 23- 28.

Karlen, D. L., and Stott. 1994. A framework for evaluating physical and chemical indicators of soil quality. In: Doran, J.W. , Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (eds). *Defining Soil Quality for a Sustainable Environment*. Soil Science Society of America, Wisconsin, USA, 35: 53- 72.

Karlen, D. L., Mausbach, M. J., Doran, J. W., Cline, R. G.,. Harris, R. F., and Schuman, G. E. 1997. Soil quality: A concept, definition, and framework for evaluation. *Soil Sci. Soc. Am. J.* 61:4-10 .

Katutis, K. and Rudzianskaitė, A. 2015. The fluctuation of calcium and magnesium concentrations in the floodwater in the Nemunas and Minija lowlands. *Zemdirbyste-Agric* 102(3): 257–264.

KAU [Kerala Agricultural University]. 2016. *Package of Practices Recommendations: Crops* (15th Ed.). Kerala Agricultural University, Thrissur, Kerala, 392p.

Kavitha, C., Sujatha, M. P., and Tata, R. 2019. Spatial variations in soil micronutrients as influenced by agro ecological conditions in a tropical humid region . *Trop. Ecol.* 60 : 362–378.

Kavitha. 2017. GIS based soil fertility mapping in agro ecosystems of Thrissur district in Kerala. PhD thesis, Cochin University of Science and Technology, Kochi.

Keen, B.A. and Raczkowski, H. 1921. Relation between the clay content and certain physical properties of a soil. *J. Agric. Sci.*11: 441-449.

Khabaz-Saberi H. and Rengel Z. 2010. Aluminum, manganese, and iron tolerance improves performance of wheat genotypes in waterlogged acidic soils. *J. Plant Nutr. Soil Sci.* 173: 461–468.

Kirk, G. 2004. The Biogeochemistry of Submerged Soils. John Wiley & Sons, Chichester. 291p.

KSBB [Kerala State Biodiversity Board]. 2019. *Impact of flood/ landslides on biodiversity community perspectives: August 2018.* Centre for management development. Thiruvananthapuram. 833p.

KSLUB [Kerala State Land Use Board]. 2014. *Natural Resources Data Book Thrissur*. Vikas Bhavan, Thiruvanathapuram. 313p.

Kumar, R. A., Aslam, M. K. M., Raj, J. V.P., Radhakrishnan, T. K. Kumar, S., K. and Manojkumar, T. K. 2016. Statistical analysis of soil fertility of Thrissur district, Kerala. In: 2016 International Conference on Data Science and Engineering, Cochin, pp 1-5.

Kumutha D., Sairam R. K., Ezhilmathi K., Chinnusamy V., and Meena R. C. 2008. Effect of waterlogging on carbohydrate metabolism in pigeon pea (*Cajanus cajan* L.): upregulation of sucrose synthase and alcohol dehydrogenase. *Plant Sci.* 175 706–716.

Larson, W.E. and Pierce. 1991. Conservation and enhancement of soil quality. In: Proceedings of the International Workshop on Evaluation for Sustainable Land Management in the Developing World. Bangkok, Thailand. International Board for Soil Research and Management. Proceedings No. 12 (2).

LeBissonnais, Y. 1996. Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. *Eur. J. Soil Sci*. 47: 425- 431.

Macé, G. O., Steinauer, K., Jousset, A., Eisenhauer, N., Scheu, S. 2016. Flood-induced changes in soil microbial functions as modified by plant diversity. *PLOS ONE* 11(11): e0166349. https://doi.org/10.1371/journal.pone.0166349

Masto, R. E., Chhonkar, P. K., Singh, D., and Patra, A. K. 2008. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilization and manuring for 31 years in the semi-arid soils of India. *Environ. Monit. Assess*.136: 419–435.

McBride, R.A., Slessor, R.L., Joosse, P.J., 2012. Estimating the particle density of clay-rich soils with diverse mineralogy. Soil Sci. Soc. Am. J. 76, 569–574.

Mielki, G.F., Novais, R.F., Ker, J.C., Vergütz, L., and Castro, G.F. 2016. Iron availability in tropical soils and iron uptake by plants. *Rev Bras Cienc Solo.* 40: 1-14.

Mishra, D. P. Behaviour of Boron in soils and plants. 1981. PhD thesis. Chhatrapati Sahuji Maharaj University, Kanpur, 194p.

Mishra, V., Aadhar, S., Shah, H., Kumar, R., Pattanail, D. R., and Tiwari, D. 2018. The Kerala flood of 2018: combined impact of extreme rainfall and reservoir storage. *Hydrol. Earth Syst. Sci. Discuss*. pp1-13.

Moeskops, B., Buchan, D., Sleute, S., Herawaty, L., Husen, E., Saraswati, R., Setyorini, D., and Neve, S. 2010. Soil microbial communities and activities under intensive organic and conventional vegetable farming in West Java, Indonesia. *Appl. Soil Ecol.* 45:112-120.

Mungai, W. N., Njue, A. M., Samuel, G. A., Said, A. H., and John, D. I. 2011. Periodic flooding and land use effects on soil properties in Lake Victoria basin. *African J. Agric. Res.* 6 (19) : 4613-4623.

Parker, F.W., Nelson, W.L., Eric, W., and Miller, I. E. 1951. The broad interpretation of soil test informations. *Agron. J.* 43: 105-110.

Pathak, H. 2010. Trend of fertility status of Indian soils. *Curr. Adv. Agric. Sci.* 2(1): 10-12.

Pathania, M. S. 2011. Livelihood Pattern of Pastoralists: A Study of Gujjars and Gaddi of Himachal Pradesh. *Indian farming* 20(11):35-38.

Patrick Jr, W. H. and Jugsujinda, A. 1992. Sequential reduction and oxidation of inorganic nitrogen, manganese, and iron in flooded soil. *Soil Sci. Soc. Am.* 56(4): 1071-1073.

Phogat , V.K., Tomar, V. S., and Dahiya, R. 2015 . Soil physical properties. In: Rattan R K., Katyal, J.C., Dwivedi, B. S., Sarkar, A.K., Bhattacharya, Tapas, Tafardar, J. C. and Kukal, S. S. (eds), *Soil Science : An Introduction* (Indian reprint, 2017). Indian Society of Soil Science, New Delhi, 873p.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. *Adv. Agron*. 24: 29-96.

Prabhavati, K. , Dasog, G.S., Patil, P.L., Sahrawat, K.L. and Wani, S.P. 2015. soil fertility mapping using GIS in three agro-climatic zones of Belgaum district, Karnataka . *J. Indian Soc. Soil Sci.* 63(2) 173-180.

Pritchett, W. L. and Fisher, R. F. 1987. *Properties and Management of Forest Soils*. (2nd Ed). John Wiley and Sons, New Jersey**,** 494p.

Quilchano, C. and Maranon, T. Dehydrogenase activity in Mediterranean forest soils. 2002. *Biol Fertil Soils* . 35: 102–107.

Raghunath, H. N. 2017. Evaluation of soil and water quality in Potta watershed of Pazhayannur block in Thrissur district. MSc (Ag) thesis, Kerala Agricultural University, Thrissur, 117p.

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

Raij, B. V., Andrade, J.C., Cantarella, H., and Quaggio, J. A. 2001. *Chemical Analysis for Assessment of Tropical Soil Fertility*. UNESP, 285p.

Rajeswar, M., Rao, C. S., Balaguravaiah, D., and Khan, M. A. A. 2009. Distribution of available macro and micronutrients in soils of Garikapadu of Krishna district of Andhra Pradesh. *J. Indian Soc. Soil Sci*. 57(2): 210-213.

Rakshit, R., Das, A., Padbhushan, R., Sharma, R. P., Sushant and Kumar, S. 2018. Assessment of soil quality and identification of parameters influencing system yield under long-term fertilizer trial. *J. Indian Soc. Soil Sci.* 66 (2): 166-171.

Ramamoorthy, B. and Bajaj, J.C. 1969. Soil fertility map of India. *Ferti. News*. 14(8) : 25.

Ramesh, V., Balloli, S. S., Sharma, K. L., Kausalya, R., Korwar, G. R., and Ramakrishna, Y. S. 2008. Characterization of soil for physical properties under different land use systems. *Indian J. Dryland Agric. Res. Dev*. 23: 102- 109.

Rani, P. S. and Latha, A. 2017. Effect of calcium, magnesium and boron on nutrient uptake and yield of rice in *Kole* lands of Kerala. *Indian J Agric. Res*. 47(3): 329-338.

Ravikumar, P. and Somashekar, R.K. 2014. Spatial distribution of macronutrients in soils of Markandeya river basin, Belgaum, Karnataka, India. In: *Proc. Int. Aca. Eco. & Environ. Sci.* 4 (2): 81-94.

Raymahashay, B.C., Rao, K.S., Mehta, V.K., and Bhavana, P.R. 1987. Mineralogy and geochemistry of lateritic soil profiles in Kerala, India. In: Y. Ogura (ed), In: Proceedings of an international seminar on laterite, October 14-17, 1985, Tokyo, Japan. *Chem. Geol*. 60: 327-330.

Rowell, D.L. 1981. Oxidation and reduction. In: Greenland, D. J. and Hayes, M.H.B. (ed.). *The Chemistry of Soil Processes*. John Wiley and Sons, Chichester. pp 401–461.

Roxy, M. S., Sumithranand, V. B. and Renuka, G. 2014. Estimation of soil moisture and its effect on soil thermal characteristics at astronomical observatory, Thiruvananthapuram, south Kerala. *J. Earth Syst. Sci*. 123(8) : 1793–1807 .

Ruehlmann, J., Körschens and Graefe, M. 2006. A new approach to calculate the particle density of soils considering properties of the soil organic matter and the mineral matrix. *Geoderma*. 130: 272-283.

Saint-Laurent, D., Paradis, R., Drouin, A., and Gervais-Beaulac, V. 2016. Impacts of floods on organic carbon concentrations in alluvial soils along hydrological gradients using a Digital Elevation Model (DEM). *Water* 8 (208): 1-17.

Sanjib, K., Behera, T., Satyanarayana and Majumdar, K. 2019. Importance of micronutrients in Indian agriculture. Arvind K. Shukla, *Better Crops - South Asia* pp 6-10.

Santhi, R., Stalin, P., Arulmozhiselvan, K. , Radhika, K., Sivagnanam, S., Sekar, J., Muralidharudu, Y., Dey, P., and Rao, A. S. 2018. Soil Fertility Appraisal for Villupuram District of Tamil Nadu using GPS and GIS Techniques. *J. Indian Soc. Soil Sci.* 66(2): 158-165.

Sanyal, J. and Lu, X.X. 2004. Application of remote sensing in flood management with special reference to Monsoon Asia: A Review. *Nat. Hazards*. 33: 283–301.

Saraf, S.A., Wani, M.H., Wani, S.A., Rauf, S.A., Baba, S.H., Shaheen, F.A., Mir, G.H., Dar, K.R. and Chattoo, M.A. 2018. Economics of saffron cultivation in Kashmir. *Acta Hortic*. 1200 :165-176.

Sathish, A. C., Ramachandrappa, B. K., Devaraja,. Savitha, M. S., Gowda, M. N. T., and Prashanth, K.M. 2018. Assessment of spatial variability in fertility status and nutrient recommendation in Alanatha cluster villages, Ramanagara district, Karnataka using GIS. *J. Ind. Soc. Soil Sci*. 66 (2): 149-157.

Schjønning, P., McBride, R. A., Keller, T., and Obour, P.B. 2017. Predicting soil particle density from clay and soil organic matter contents. *Geoderma* 286:83-87.

Schjønning, P., McBride, R.A., Keller, T., and Obour, P.B. 2017. Predicting soil particle density from clay and soil organic matter contents. *Geoderma*. 286 :83-87.

Shabala S. 2011. Physiological and cellular aspects of phytotoxicity tolerance in plants: the role of membrane transporters and implications for crop breeding for waterlogging tolerance. *New Phytol.* 190: 289–298.

Shah, D. 2010. Cultivation Practices of Strawberry in the Western Hilly Tracts of Maharashtra: Prospects and Emerging Issues. Conference: 70th Annual Conference of the Indian Society of Agricultural Economics At: University of Jammu, Jammu, India. Volume: 65

Shakhila, S.S. and Mohan, K. 2014. Study of heavy metal contamination on soil and water in major vegetable tracks of Pathanamthitta district, Kerala, India. *Int. J. Eng Sci. Invention.* 3 (2): 34-39.

Sheeja, S. 1994. Micronutrient status and their distribution in major tuber crops growing soils of India in relation to soil properties. Msc (Chem) thesis. University of Kerala, Thiruvananthapuram, 188p.

Shetty, Y.V., Nagamma, M.S., Dineshkumar, M. and Jayaprakash, S. M. 2008. Fertility status in arecanut garden soils of Karnataka. *Karnataka J. Agric Sci.* 21: 503-506.

Shyju, K. and Kumaraswamy, K. 2017. Physicochemical characteristics of soils of Talapilli taluk, Thrissur, Kerala, India. *Saudi J. Humanities*. *Soc. Sci*. 2 (11B): 1126-1135.

Singh, K, Bordoloi, L. J., Kumar, M., Hazarika S., and Brajendra Parmar. 2014. Land use impact on soil quality in eastern Himalayan region of India. *Environ Monit*. 186(4): 2013-24.

Skjemstad. J.O., L.J. Janik, M.J. Head, and S.G. McClure. 1993. High energy ultraviolet photo-oxidation: A novel technique for studying physically protected organic matter in clay- and silt-sized aggregates. *J. Soil Sci*. 44:485-499.

Spices Board: Annual Report 2018-19, Spice Statistics. Available: http://www.indianspices.com.

Spreafico, M. 2006. Flash floods in mountain areas. Climate Variability and Change—Hydrological Impacts (Proceedings of the Fifth Friend World Conference held at Havana, Cuba, November 2006), IAHS Publ. p232-238

SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc.

SSOA. 2007. Bench mark soils of Kerala. Soil Survey Organization Agriculture Department. Govt. of Kerala. Thiruvananthapuram. 623p.

SSSA [Soil Science Society of America]. 2009. Impact of floods on soils. Science Daily[online].Available:http://www.sciencedaily.com/releases/2009/04/090408 140204.htm [23 April 2020].

Subbiah, B. and Asija, G. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Current Sci*. 25: 259-260.

Subhani, A., Changyong, H., Zhengmiao, Y., Min, L., and El-ghamry, A. 2001. Impact of soil environment and agronomic practices on microbial/dehydrogenase enzyme activity in soil. *Pakistan J. Biol. Sci.* 4: 333-338.

Sujatha MP, Bindhu PS, Sandeep S, Sureshkumar P, Kavitha C and Remya EB (2013) Soil fertility: Thrissur District, Soil fertility assessment and information management for enhancing crop productivity in Kerala (eds. P. Rajasekharan, K.M. Nair, G. Rajasree, P. Suresh Kumar and M.C Narayanankutty), Kerala State Planning Board, Thiruvanathapuram, pp 419–442

Sumner, M. E. 1992. The electrical double layer and clay dispersion. In : Sumner, M. E. and Stewart, B. A. (eds.). *Soil Crusting: Chemical and Physical Processes.* Adv. Soil Sci. Lewis Publishers. Boca raton. pp1-31.

Tamai, K. 2010. Effects of environmental factors and soil properties on tropographic variations of soil respiration. *Biogeo. Sci*. 7:1133–1142.

Tesfahunegn, G. 2014. Soil quality assessment strategies for evaluating soil degradation in Northern Ethiopia. *Appl. Env. Soil Sci*. 2014:1-14.

Thien, S. J. 1979. A flow diagram for teaching texture by feel analysis. *J. Agron. Edu.* 8: 54-55.

Tian, J., Dong, G., Karthikeyan, R., Li, L., and Daren, H. R. 2017. Phosphorus dynamics in long-term flooded, drained, and reflooded soils. *Water* 9(531):1-13.

Trevors, J. 1984. Effect of substrate concentration, inorganic nitrogen, oxygen concentration, temperature and pH on dehydrogenase activity in soil, plant and soil. *Plant and Soil* 77 (2): 285-293.

Truman, C. C., Bradford, J. M., and Ferris, J. E. 1990. Antecedent water content and rainfall energy influence on soil aggregate breakdown. *Soil Sci. Soc. of Am. J.* 54(5): 1385-1392.

Truog, E. 1945. Determination of total and available boron in soils . *Soil Sci*. pp 59185-90.

Tsheboeng, G., Bonyongo, M., and Murray-Hudson, M. 2014. Flood variation and soil nutrient content in floodplain vegetation communities in the Okavango delta. *S. Afr. J. Sci.* 110 (3/4): 1-5.

Unger, I. M., Peter, P., Motavalli, P. P., and Muzika, R. 2009. Changes in soil chemical properties with flooding: A field laboratory approach. *Agric. Ecosyst. Environ*. 131:105–110.

Unni , P. N., Santhakumar, G. and Nair, S. R. 1995. Metal toxicity in acid soils of Kerala —effect of manganese on growth and physiology of rice (*Oryza sativa* L. cv. Jaya). *Int. J. Environ. Studies*. 47(2): 151-158.

Vashisht , B. B., Maharjan, B., Sharma, S., and Kaur, S. 2020. Soil quality and its potential indicators under different land use systems in the Shivaliks of Indian Punjab. *Sustainability*: 12: 3490.

Venkatesh, B., Lakshman, N., Purandara B.K., and Reddy, V.B. 2001. Analysis of observed soil moisture patterns under different land covers in Western Ghats, India. *J. Hydrol*. 397 (3–4)281–294.

Vishnu C.L., Sajinkumar, K.S., Oommen, T., Coffman, R.A., Thrivikramji, K.P. , Rani ,V.R. and Keerthy, S. 2019. Satellite-based assessment of the August 2018 flood in parts of Kerala, India. *Geomatics, Natural Hazards and Risk*. 10(1): 758-767.

Walkley, A. J. and Black, I.A. 1934. Estimation of soil organic carbon by the chromic acid titration method. *Soil Sci*. 37: pp 29-38.

Wani, S.A. and. Mir, M.S. 2010. Land based economy of cold arid Ladakh. *Indian J. Agric. Econ.*

Wolinska, A. 2010. Dehydrogenase activity of soil microorganisms and oxygen availability during reoxidation process of the selected mineral soils from Poland. *Acta Agrophysica* 180- 188.

Wolińska, A. and Stępniewska, Z .2012. Dehydrogenase activity in the soil environment. *Intech Open* 8: 183–210.

Xu, M., Zhao, Y., Liu, G., Robert, M., and Argent. 2006. Soil quality indices and their application in the hilly loess plateau region of China. *Australian J. Soil Res*. 44: 245–254.

Yua, P., Hanb, D., Liua , S., Wena, X., Huanga, Y., Jiab, H. 2018. Soil quality assessment under different land uses in an Alpine grassland. Catena 171: 280-287.

Yuan, B. and Yue, D. 2012. Soil microbial and enzymatic activities across a chronosequence of chinese pine plantation development on the loess plateau of china. *Pedosphere* 22: 1-12.

Yu-Dong, C., Huo-Yan, W., Jian-Min, Z., Lu,X., Bai-Shu, Z., Yong-Cun, Z., and Xiao-Qin, C. 2013. Minimum data set for assessing soil quality in farmland of northeast China. *Pedosphere* 23(5): 564–576.

Zhang, N., He, X., Gao, Y., Li, Y., Wang, H., Ma, D., Zhang, R., and Yang, S. 2010. Pedogenic carbonate and soil dehydrogenase activity in response to soil organic matter in *Artemisia ordosica* community. *Pedosphere* 20(2): 229-235.

APPENDICES

Appendix I. Questionnaire for post- flood survey of AEU 15 in Thrissur district

KERALA AGRICULTURAL UNIVERSITY
COLLEGE OF HORTICULTURE, VELLANIKKARA
Department of Soil Science and Agricultural Chemistry

PROFORMA

I. General information

1. **Name of the farmer :**
2. **Name of panchayat :**
3. **Address of the farmer :**
4. **Land area :**
5. **Contact no. :**
6. **Latitude :**
7. **Longitude :**
8. **Survey no. :**
9. **Social affiliation :**
10. **Email ID :**

II Socio economic details

1. **Size of family :**
2. **Literacy status :**
3. **Occupation :**
4. **Other allied activities, if any :**

III. Crop details

1. **Present crop in the field :**
2. **Cropping pattern :**
3. **Yield of respective crops grown :**
4. **Source of irrigation :**
5. **Whether infested with pest or diseases :**
6. **Whether any credit availed (short/ medium/long term) :**
7. **Whether any cottage industry owned :**
8. **Major problem encountered in crop production :**
9. **Estimate of agricultural losses due to floods :**
10. **Reasons for changes in cropping pattern, if any :**
11. **Nearest market :**

IV. Flood details

1. **Duration of flood :**
2. **Source of flood :**
3. **Whether any crusting / hard pan observed:**

Appendix II. Geographical coordinates of locations of soil sampling sites in AEU 15 of Thrissur district

a. Pazhayannur panchayat

Sample no.	Name of the farmer	Latitude	Longitude	Elevation (m)
1	Paulose Thadathil	10° 40' 18.8" N	76° 24' 43.0" E	81.5
2	Lakshmikkutty Paalekkal	10° 39' 36.4" N	76° 24' 52.5" E	58.8
3	Ibrahim Kumlealo	10° 39' 29.9" N	76° 25' 01.5" E	68.3
4	Sulaiman Panthalamkondparamb	10° 39' 44.6" N	76° 24' 57.9" E	51.4
5	Paulose Pachilakkattil	10° 39' 41" N	76° 25' 05.9" E	55.9
6	Rajendran Prasad	10° 40' 10.5" N	76° 25' 27.4" E	61.2
7	Hassnar Paarakkal	10° 39' 41.9" N	76° 25' 09.4" E	56.1
8	Abdul Rahman Chemmatpuram	10° 39' 43.5" N	76° 25' 03.7" E	56.3
9	Janeesa Thekkethil	10° 39' 19.5" N	76° 25' 19.8" E	61.4
10	Vineesh	10° 39' 20.6" N	76° 25' 36.0" E	58.7
11	Safiya Vattaparakkalam	10° 38' 45.4" N	76° 24' 37.5" E	78.3
12	Vincent Perungattu	10° 38' 09.9" N	76° 24' 00.2" E	81
13	Sujitha	10° 37' 36.7" N	76° 23' 47.1" E	66.1
14	Muralidharan Rariyam Kandam	10° 36' 57.4" N	76° 23' 33.0" E	67.3
15	Paulose Nellimattathil	10° 36' 34.2" N	76° 23' 19.0" E	82.1

b. Pananchery panchayat

Sample no.	Name of farmer	Latitude	Longitude	Elevation (m)
1	Mohandas	10° 32' 53.41" N	76°19' 14.05" E	24.8
2	Satyan	10° 32' 52.85" N	76°19' 11.49" E	28.7
3	Simon	10° 38' 3.87 " N	76°19' 4.21" E	58.2
4	Kurian	10° 32' 59.43" N	76°19' 17.19" E	21.8
5	Joy Theninkal	10° 32' 48.69" N	76°19' 21.09" E	20.7
6	Mayali Jose	10° 32' 50.68" N	76°19' 16.46" E	15.7
7	Idinjapilli Sreedharan	10° 32' 35.41" N	76°19' 17.01" E	21.9
8	Simon	10° 32' 37.18" N	76°19' 8.05" E	19.4
9	Prakashan	10° 32' 45.80" N	76°19' 29.4" E	33.8
10	Thankappan	10° 32' 34" N	76°19' 22.82" E	22.1
11	Shanthappan	10° 32' 55.17" N	76°20' 14.96" E	22.8
12	Jose Chaarakkunnu	10° 33' 0.11"N	76°20' 9.43" E	27.7
13	Roy Kulangara	10° 33' 3.08" N	76°20' 8.82" E	25.3
14	Aji Mekunpara	10° 33' 7.83" N	76°20' 5.55" E	26.3
15	John	10° 32' 52.00" N	76°20' 15.32" E	24.3
16	Sunny Cherayath	10° 32' 47.23" N	76°20' 30.38" E	23.2
17	Sister Sonita(Ursuline convent)	10° 32' 46.79" N	76°20' 34.07" E	25.7
18	Konganammoola Balan	10° 32' 48.24 " N	76°20' 54.93" E	29.2
19	Velappan	10° 32' 38.76" N	76°20' 51.66"E	28.4
20	Parnayil Paulose	10° 32' 27.85" N	76°20' 58.24" E	30.8
21	Alex Plakkeezhil	10° 32' 15.1" N	76° 18' 51.6" E	20.6
22	Geevarghese	10° 32' 30.69" N	76° 19' 1.13" E	25.4
23	Thengamoochi Sasi	10° 32' 41.79" N	76° 19' 5.49" E	17.4
24	Mohanan Kudiyakkottil	10° 33' 17.1" N	76°20' 28.9" E	21.4
25	Chitra Korapath	10° 33' 23.3 " N	76°20' 39" E	26.8
26	Mundopuram Parameswaran	10° 33' 30.1" N	76°20' 12.6" E	29.9
27	Kuttan	10° 33' 15.6" N	76° 19' 14.8" E	20.1
28	Adv Raghu	10° 33' 27.8" N	76° 19' 08.7" E	23
29	Joy Neelankavil	10° 33' 52.2" N	76° 19' 15.6" E	34.9
30	Aneesh Joy Neelankavil	10° 33' 53.5" N	76° 19' 14.8"E	35.4

c. Puthur panchayat

Sample no.	Name of farmer	Latitude	Longitude	Elevation (m)
1	Kaladharan Alandrankavil	10° 29' 45.7" N	76° 16' 28.9" E	13.1
2	Mohanan Kalladathil	10° 29' 29.2" N	76° 16' 29.1" E	15.2
3	Prakashan chandrika	10° 29' 19.0" N	76° 16' 29.1" E	18.9
4	Sachidanandan	10° 28' 56.4" N	76° 16' 07.3" E	14.9
5	Sheby	10° 28' 31.7" N	76° 16' 59.4" E	24.2
6	Preman thazhath	10° 28' 08.2" N	76° 16' 05.1" E	13.3
7	Dinesh Chandravilasam	10° 27' 47.6" N	76° 16' 00.7" E	16.1
8	George Kalappura	10° 28' 52.4" N	76° 16' 13.0" E	15
9	Santhosh Nedumparambil	10° 28' 28.4" N	76° 16' 25.8" E	11.9
10	Jayarajan Chakkedath	10° 28' 56.9" N	76° 16' 13.5" E	12.6
11	Vasu Chelamparambil	10° 28' 57.6" N	76° 16' 19.4" E	11.5
12	Dharman	10° 28' 41.6" N	76° 16' 26.6" E	11.3
13	Subin Moorkkanattil	10° 28' 49.1" N	76° 16' 46.9" E	9.5
14	Kuttan	10° 28' 48.7" N	76° 17' 44.7" E	17.4
15	Sudhakaran Thoppil	10° 28' 49.1" N	76° 16' 46.9" E	9.5
16	P C Thomas Pulloopparambil	10° 28' 45.1" N	76° 17' 35.0" E	20.8

d. Varantharappilly panchayat

Sample no.	Name of farmer	Latitude	Longitude	Elevation (m)
1	Vijayan Chengadanparambil	10° 25' 20.7" N	76° 22' 06.3" E	22.4
2	Danny Kottamparambil	10° 25' 16.1" N	76° 22' 00.2" E	17.7
3	Johnson Naduvilpedia	10° 25' 38.9" N	76° 21' 50.2" E	24.9
4	Sarojam Pallathi	10° 25' 49.5" N	76° 22' 06.1" E	20.1
5	Chakkunni	10° 25' 32.0" N	76° 21' 45.86" E	22
6	Bhaskaran Chemmandaparambil	10° 25' 23.3" N	76° 21' 13.6" E	18.8
7	Attepadan Rajan	10° 25' 33.9" N	76° 21' 19.8" E	17.3
8	Raghunathan Kaniyamparambil	10° 25' 26.7" N	76° 21' 05.2" E	19
9	Magenta Shine	10° 25' 07.3" N	76° 20' 44.8" E	20.5
10	Abdutty Haji	10° 25' 21.9" N	76° 20' 24.4" E	10.1
11	Sudhakaran Vettiyadan	10° 24' 50.8" N	76° 20' 02.1" E	18.5
12	P Ramachandran Vattathil	10° 24' 21.4" N	76° 19' 49.7" E	19.6
13	Nandakumar Kummanotttmadan	10° 24' 07.7" N	76° 19' 49" E	13.2
14	Pushkaran Thekkumpuram	10° 24' 10.5" N	76° 19' 55.5" E	19.8
15	Libin Babu Chelliparamb	10° 23' 60.0" N	76° 19' 41.6" E	14.8
16	Byju Chelipparambil	10° 23' 33.8" N	76° 19' 33.8" E	10
17	Byju	10° 23' 34.0" N	76° 19' 23.4" E	8.5
18	Prabhakaran Eleyedath	10° 23' 31.7" N	76° 19' 53.6" E	19
19	Gopalakrishnan Vaattathil	10° 23' 13.7" N	76° 19' 41.8" E	17.5
20	Santhosh Nair Kadayath	10° 23' 18.5" N	76° 19' 48.5" E	16.6
21	Surendran P B ,Pattikkattil	10° 23' 25.2" N	76° 20'00.2" E	18.7
22	Vijayan Kanjili	10° 23' 41.4" N	76° 19' 39.5" E	17.3

e. Mattathur panchayat

Sample no.	Name of farmer	Latitude	Longitude	Elevation (m)
1	Pandiyalikkal Velayudan	10° 21' 24.1" N	76° 24' 42.7" E	24.4
2	Kunnath Yacoub	10° 21' 23.3" N	76° 24' 44.0" E	22.2
3	Nirappilal Babu	10° 21' 32.8" N	76° 24' 06.8" E	27.6
4	K T Varghese	10° 22' 01.1" N	76° 22' 38.7" E	13.9
5	Subran Pallivaluppil	10° 22' 01.5" N	76° 22' 32.9" E	13.2
6	Annie Davis	10° 22' 43.3" N	76° 21' 29.6" E	15.7
7	Vinod	10° 22' 32.3" N	76° 21' 19.8" E	15
8	Kalapurakkal Aravindakshan	10° 22' 40.44" N	76° 21' 03.7" E	14.5
9	Augustine	10° 22' 49" N	76° 21' 08.0" E	14.1
10	Saraswathy	10° 22' 51.8" N	76° 20' 39.9" E	12.6
11	George K	10° 22' 55" N	76° 20' 38.3" E	12.1
12	Palazhi Arun	10° 23' 11.3" N	76° 20' 02.3" E	13.8
13	Thekkedath Gopalakrishnan	10° 23' 08.7" N	76° 20' 06.7" E	12.1
14	Shantha	10° 23' 00.6" N	76° 19' 37.8" E	19.2
15	Pallatheri	10° 23' 02.2" N	76° 19' 38.5" E	15.2
16	Kanakavalli	10° 22' 58.4" N	76° 19' 27.6" E	17.8
17	Achyuthan	10° 23' 00.2" N	76° 19' 09.5" E	15.4
18	Hariharan Kariyattil	10° 23' 04.3" N	76° 18' 52.5" E	10.6
19	Shankaran Nair	10° 23' 19.6" N	76° 18' 52.8" E	16.3
20	Paulson	10° 23' 26.6" N	76° 18' 44.9" E	12.2
21	Jint	10° 23' 24.3" N	76° 18' 26.2" E	15

Appendix III. Soil fertility ratings for organic carbon, primary, secondary and micronutrients

a. Organic carbon and primary nutrients

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

b. Secondary nutrients

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

c. Micronutrients

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

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

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

e. Ratings for Relative Soil Quality Index (RSQI)

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

Appendix IV.

1. Lime and fertilizer recommendations for different panchayats in AEU 15 of Thrissur district

a. Lime requirement

Soil reaction	Soil pH	Lime requirement (kg $CaCO_3$)
Very strongly acidic	4.5- 5.0	600
Strongly acidic	5.1- 5.5	350
Moderately acidic	5.6 – 6.0	250
Slightly acidic	6.1 - 6.5	100
Neutral	6.5 - 7.3	0

b. Fertiliser recommendation for available nitrogen, phosphorus and potassium (KAU, 2016)

Soil fertility class	Organic carbon (%)	N as % of general recommendation	Available P	Available K	P and K as % of general recommendation
0	0.00 - 0.16	128	0.0 – 3.0	0-35	128
1	0.17 - 0.33	117	3.1- 6.5	36-75	117
2	0.34 – 0.50	106	6.6- 10.0	76-115	106
3	0.51 – 0.75	97	10.1 – 13.5	116-155	94
4	0.76 – 1.00	91	13.6- 17.0	156- 195	83
5	1.01 – 1.25	84	17.1- 20.5	196-235	71
6	1.26 -1.50	78	20.6- 24.0	236- 275	60
7	1.51- 1.83	71	24.1- 27.5	276- 315	48
8	1.84 – 2.16	63	27.6- 31.0	316-355	37
9	2.17 – 2.50	54	31.1 – 34.5	356- 395	25

c. Fertilizer recommendation for secondary nutrients and micronutrients

Nutrient	Recommendation (KAU, 2016)
Available calcium	As per lime recommendation
Available magnesium	80 $MgSO_4$ ha^{-1}
Available sulphur	25 kg S ha^{-1}
Available boron	10 kg Borax ha^{-1}

Appendix V. Summary statistics of soil properties of AEU 15 in Thrissur district.

Parameter	Minimum	Maximum	Mean	SD	SE
Bilk density (Mg m $^{-3}$)	0.83	1.74	1.33	0.17	0.02
Moisture content (%)	6.19	59.44	23.84	8.25	0.81
Particle density (Mg m $^{-3}$)	2.04	2.99	2.50	0.21	0.02
Porosity (%)	25.90	67.10	46.41	7.55	0.74
MWHC (%)	29.28	57.88	43.89	6.05	0.59
pH	4.48	6.75	5.67	0.58	0.06
Ex. Acidity (cmol kg^{-1})	0.80	2.50	1.80	0.60	0.06
EC(dS m^{-1})	0.02	0.15	0.05	0.02	0.002
OC (%)	0.19	2.24	0.94	0.40	0.04
Available N (kg ha^{-1})	100.35	539.39	172.36	53.76	5.27
Available P (kg ha^{-1})	15.77	762.54	231.88	192.67	18.89
Available K (kg ha^{-1})	53.20	648.59	241.34	104.74	10.27
Available Ca (mg kg^{-1})	298.10	2118.00	740.68	325.80	31.95
Available Mg (mg kg^{-1})	30.70	403.20	142.60	68.11	6.68
Available S (mg kg^{-1})	0.40	55.09	6.46	6.63	0.65
Available Fe (mg kg^{-1})	15.43	239.40	72.10	43.71	4.29
Available Mn (mg kg^{-1})	6.04	117.00	37.20	25.56	2.51
Available Cu (mg kg^{-1})	0.84	16.37	4.40	2.63	0.26
Available Zn (mg kg^{-1})	1.22	21.57	4.31	2.77	0.27
Available B (mg kg^{-1})	0.003	0.298	0.030	0.035	0.003
DHA (µg TPF g^{-1} 24 hr^{-1})	0.23	477.37	120.29	104.53	10.25

Appendix VI. Comparison of pre flood and post flood soil characteristics of AEU 15

Sl no.	Parameter	Fertility class	Percent samples	
			Pre flood ** (KSHIS,2013)	Post flood
1	pH	Very strongly acid (4.5-5.0)	38	14.42
		Strongly acid	36	31.73
		Moderately acid	19	27.88
		Slighthly acid	7	17.31
		Neutral	0	8.65
2.	Organic carbon	Low	21	39.4
		Medium	40	53.8
		High	39	16.3
3	Available N	Low	6 *	97.12
		High	94*	2.88
4.	Available P	Low	17	0
		Medium	23	0
		High	60	100
5	Available K	Low	68	9.62
		Medium	20	58.65
		High	12	31.73
6	Available Ca	Deficient	55	0.96
		Sufficient	45	99.04
7	Available Mg	Deficient	78	40.38
		Sufficient	22	59.62
8	Available S	Deficient	42	58.65
		Sufficient	58	31.73
9	Available Cu	Deficient	6	0.96
		Sufficient	94	99.04
10	Available Zn	Deficient	10	0
		Sufficient	90	100
11	Available B	Deficient	55	100
		Sufficient	45	0

Appendix VII. Rock type, soil mapping unit and description of major soils in AEU 15 of Thrissur district

Panchayat	Rock type	Mapping unit	Description of major soil	Major soil	Inclusions
Pazhayannur	Metamorphic	K 11 Midland	Very deep, well drained, gravelly clay soils on gently sloping midland laterites with valleys of central Kerala, with moderate erosion. Associated with deep, well drained, clayey soils with coherent material at 100 to 150 cm on gentle slopes.	Clayey, Kaolinitic, Ustic Kandihumults Clayey, Kaolinitic, Typic Kanhaplustults	Fine Mixed Typic Dystropepts Clayey–skeletal, Kaolinitic, Oxic Humitropepts
Pananchery	Metamorphic and plutonic	K 33 South Sahyadri	Deep, well drained, gravelly clay soils on moderately sloping medium hills with thin vegetation, with severe erosion Associated with rock outcrops	Fine, Kaolinitic, Oxic Humitropepts Rock land	Fine , Mixed, Ustic Humitropepts Fine–loamy Mixed, Ustic Palehumults
Puthur	Metamorphic and plutonic rocks				
Varantharappilly	Metamorphic and plutonic rocks	K 31 South Sahyadri	Very deep, well drained, gravelly loam soils on steeply sloping medium hills with thick vegetation, with moderate erosion Associated with very deep, well drained, clayey soils on moderate slopes	Fine-loamy, Mixed Ustic Humitropepts Clayey –mixed Ustic Palehumults	Rock land Clayey-mixed Ustic Haplohumults
Mattathur	Metamorphic and plutonic rocks	K 38 South Sahyadri	Very deep, well drained, clayey soils on moderately steeply sloping high hills with thin vegetation, with moderate erosion Associated with rock outcrops	Clayey , Mixed, Ustic Palehumults Rock land	Fine , Mixed, Ustic Humitropepts Fine-loamy, Mixed, Ustic Humitropepts

(KSLUB, 2014)

ASSESSMENT OF SOIL QUALITY IN THE POST FLOOD SCENARIO OF AEU 15 (NORTHERN HIGH HILLS) IN THRISSUR DISTRICT OF KERALA AND MAPPING USING GIS TECHNIQUES

By

MILI M.
(2018 – 11 – 024)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR – 680656
KERALA, INDIA
2020

Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques.

Abstract

Agro-ecological unit 15 (AEU 15) represents the Northern High Hills which is characterised by long dry spells (4 months in a year), a tropical humid monsoon type climate with an average annual precipitation of 3459.5 mm and a mean annual temperature of 26.2^0 C. The hilly terrains have deep, well drained clayey soils rich in organic matter, strongly acidic and low in bases whereas the valleys have deep, imperfectly drained acid clayey soils. The August floods of 2018 had caused great havoc to life, property and agriculture of the state causing drastic changes in soil properties thereby affecting soil quality and fertility and thereby its productivity.

The study entitled 'Assessment of soil quality in the post flood scenario of AEU 15 (Northern High Hills) in Thrissur district of Kerala and mapping using GIS techniques' was therefore conducted with an objective to assess soil quality in the designated AEU and prepare thematic maps using GIS. A total of one hundred and four geo-referenced soil samples were collected from five grama panchayats namely Pazhayannur, Pananchery, Puthur, Varantharappilly and Mattathur, which were affected by floods. These soils were characterized for physical, chemical and biological properties.

The bulk density values ranged from 0.83 to 1.74 Mg m^{-3} and 80.77% of the soils had a bulk density greater than 1.20 Mg m^{-3}. Porosity ranged between 30 to 60% in 99.04 per cent of the samples and 83.65 per cent of the samples had maximum water holding capacity in the range of 30-50 %. Among the soil samples, 53.84 per cent belonged to moderately acidic /slightly acidic/neutral category (pH $\geq$ 5.6). All the soils had electrical conductivity less than 1.0 dS m^{-1}. Exchangeable acidity was greater than 1 cmol kg^{-1} in 81.73% of the samples. In case of organic carbon, 39.40 per cent of the samples had low (< 0.75%) and 53.80 per cent of the samples had a medium (0.75- 1.50 %) organic carbon content. Available nitrogen content was low (< 280.0 kg ha^{-1}) in 97.12 per cent of the samples whereas available phosphorus

content was high (>25.0 kg ha^{-1}) in all the samples. In the case of available potassium, 58.65 per cent of the samples had medium (116.0 -275.0 kg ha^{-1}) and 31.73 per cent had high (>275.0 kg ha^{-1}) contents.

Available calcium content was sufficient (>300 mg kg^{-1}) in 99.04 per cent of the samples. Deficiency of available magnesium (<120 mg kg^{-1}) was found in 59.62 per cent of the samples. In case of available sulphur, 58.65% of samples were deficient. All the soils were sufficient in terms of available micronutrients viz., iron, manganese, copper and zinc. But all the samples were deficient in available boron. In 42.30 per cent of the samples, dehydrogenase activity was less than 75 μg TPF g $^{-1}$ 24 hr^{-1}. Nutrient indices of flood affected areas in AEU 15 in Thrissur district were low (<1.67) with respect to available nitrogen; medium (1.67- 2.33) with respect to organic carbon and available potassium and high (>2.33) with respect to available phosphorus.

Using principal component analysis (PCA), seven principal components with eigen values greater than one were extracted and eight soil parameters were identified as the key indicators determining the soil quality of the area. The key indicators formed the minimum data set (MDS) viz., porosity, water holding capacity, pH , available nitrogen, potassium, magnesium, manganese and boron. Non linear scoring method was adopted to assess soil quality. The products of score and weightage factor of the MDS parameters were summed up to obtain a soil quality index (SQI) of that particular site. Soil quality indices were rated using relative soil quality index (RSQI). It was found that 79.81 per cent of the soil samples had a medium relative soil quality index .

Organic carbon showed a significant positive correlation with available nitrogen, zinc, magnesium, copper, maximum water holding capacity and dehydrogenase activity. In comparison with preflood data (GoK, 2013) where all samples were found to be acidic (pH 4.50- 6.50), 8.65% of the post flood soils exhibited neutral range of pH. Organic carbon, available nitrogen, sulphur and boron became more deficient after the floods. But there was an increase in the content of nutrients like available phosphorus, potassium, calcium, magnesium, copper and zinc. Bulk density of soils also increased after the floods. The soil quality of post flood soils in the AEU have to be improved by adopting site specific and integrated nutrient management practices in a comprehensive manner including fertilizers, organic sources and biofertilizers.