SOIL QUALITY ASSESSMENT AND GENERATION OF GIS MAPS IN FLOOD AFFECTED MANANTHAVADY BLOCK OF WAYANAD DISTRICT

FOUSIYA P.V.

(2018-11-072)

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE

PADANNAKKAD, KASARAGOD - 671314

KERALA, INDIA

2020

SOIL QUALITY ASSESSMENT AND GENERATION OF GIS MAPS IN FLOOD AFFECTED MANANTHAVADY BLOCK OF WAYANAD DISTRICT

by

FOUSIYA P.V.

(2018-11-072)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE

IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE, PADANNAKKAD

KASARAGOD – 671314

KERALA, INDIA

2020

DECLARATION

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

Padannakkad

Date: 18/9/20

FOUSIYA P.V.

(2018-11-072)

CERTIFICATE

Certified that this thesis, entitled **"SOIL QUALITY ASSESSMENT AND GENERATION OF GIS MAPS IN FLOOD AFFECTED MANANTHAVADY BLOCK OF WAYANAD DISTRICT"** is a record of research work done by independently by Ms. Fousiya P.V. (2018-11-072) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Padannakkad

Date: 18/9/20

Dr. P.R. Suresh

(Major Advisor, Advisory Committee)

Associate Dean, Professor& Head

Department of Soil Science and

Agricultural Chemistry

College of Agriculture

Padannakkad, Kasaragod

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Fousiya P.V.** (2018-11-072) a candidate for the degree of **Master of Science in Agriculture** with major in **Soil Science and Agricultural Chemistry**, agree that this thesis entitled **"SOIL QUALITY ASSESSMENT AND GENERATION OF GIS MAPS IN FLOOD AFFECTED MANANTHAVADY BLOCK OF WAYANAD DISTRICT"** may be submitted by **Ms. Fousiya P.V.** (2018-11-072), in partial fulfilment of the requirement for the degree.

Dr. P.R. Suresh
(Chairman, Advisory committee)
Associate Dean, Professor & Head
Department of SS&AC
College of Agriculture, Padannakkad
Kasaragod-671314

Dr. N.K. Binitha
(Member, Advisory committee)
Assistant Professor
Department of SS&AC
College of Agriculture,
Padannakkad
Kasaragod-671314

Dr. Jayaraj. P
(Member, Advisory committee)
Assistant Professor
(Programme coordinator)
Department of SS&AC
KVK, Panniyur
Kannur-670142

Smt. Geetha Radhakrishnan
(Member, Advisory committee)
Assistant Professor
Department of Computer Science
College of Agriculture,
Padannakkad
Kasaragod- 671314

Acknowledgement

"Alhamdulillah"

First and foremost I bow my head before Allah for all the blessings showered upon me throughout my life and for the perseverance bestowed upon me especially during the course of my research work.

It is with great respect I express my deep sense of gratitude and indebtedness to ***Dr. P. R. Suresh****, Associate Dean, Professor and Head, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Padannakkad and Chairman of my Advisory Committee for his expert advice, valuable suggestions, inspiring guidance, enthusiastic approach, constructive criticisms, thought provoking discussions, unreserved help and kind concern during the conduct of this research work and preparation of thesis. I value his knowledge and wisdom which nurtured this research in right direction without which fulfillment of this endeavor would not have been possible. I really consider it my greatest fortune in having his guidance for my research work.*

With immense pleasure, I extend my sincere gratitude and reverence to ***Dr. N.K. Binitha,*** *Assistant Professor, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Padannakkad, and member of Advisory Committee, for her expert guidance, patient hearing, constructive criticisms, valuable suggestions and above all her support and encouragement throughout the course of study.*

I sincerely thank ***Dr. Jayaraj. P,*** *Assistant Professor, Programme coordinator, Department of Soil Science and Agricultural Chemistry, KVK Kannur and member of Advisory Committee for his valuable guidance and suggestions during the course of research work.*

I am indebted to ***Smt. Geetha Radhakrishnan,*** *Assistant Professor, Department of Computer Science, College of Agriculture, Padannakkad, and member of Advisory Committee, for her critical evaluation of manuscript, constant encouragement, sincere help and support in times of need especially in the preparation of this thesis.*

I express my esteemed gratitude to my teachers, ***Dr. Nitheesh. P,*** *and* ***Sri. Shameer Mohammed. E,*** *for their esteemed advice, timely help, and valuable* *suggestions throughout this programme. I greatly acknowledge the invaluable help received from* ***Mubarak ikka*** *and all the non-teaching staff of our department* ***Ramyechi, Manju chettan, Sukileattan, Dheepthi chechi, Joona chechi, Sreelakshmi,*** *and* ***Mohanettan*** *throughout my venture.*

I express my special thanks to ***Mr. Varghees,*** *farmer, Mananthavady and* ***Santhoshettan*** *for their co-operation and the valuable time spent to help me during the survey.*

I would like to express my sincere thanks to my best classmates, ***Shu, Hasu, Nimya, Deepa, Sugina, Veena, Nayana, Anuprasadh, Lintu, Karishma, and Haritha*** *for their, moral support and sharing their part during my hard times during this course of study.*

I am ever grateful to my seniors ***Gladis chechi, Roshni chechi, Anu chechi, Pathu, Jaseeratha, Giffy chechi, Amalenduettan, Wayo chettan, Sajayettan, Radhika chechi, Reshma chechi, Adarsh chettan, Akhilettan, Vinayak chettan, Shibin chattan*** *and* ***Chethan chettan*** *and my juniors* ***Amaya, Anji, Ramya*** *and* ***Arya*** *for their constant help and encouragement that made me confident in difficult situation.*

I am greatly beholden of vocabulary and owe a deep sense of honour to my beloved father ***Mr. Ali,*** *mother* ***Smt. Fareeda,*** *sisters* ***Aizu, Rifa, Asma*** *and my relatives for their constant prayers, affection, moral support, personal sacrifice and sincere encouragement throughout the period of my studies.*

Tis thesis became a reality with the kind support and help of many individuals. I would like to extend my thanks to all of them.

Fousiya P. V.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

%	- percent
ºC	- degree Celsius
µg	- microgram
AEU	- Agro-ecological Unit
AHP	- Analytical Hierarchy Process
ANOVA	- Analysis of Variance
B	- Boron
BD	- Bulk density
Ca	- Calcium
Cd	- Cadmium
CEC	- Cation exchange capacity
CTCRI	- Central Tuber Crops Research Institute
cm	- centimeter
cmol (p^{+}) Kg^{-1}	- centimole of positive charge per kilogram
Cr	- Chromium
Cu	- Copper
DA	- Discriminant analysis
dS m^{-1}	- deci Siemen per meter
EC	- Electrical Conductivity
ECEC	- Effective cation exchange capacity
et al.	- and others
Ex. Acidity	- Exchangeable acidity
Ex. Al	- Exchangeable aluinium
Ex. Na	- Exchangeable sodium
Fe	- Iron
Fig.	- Figure
g	- gram

GIS	- Geographic Information System
GOK	- Government of Kerala
GPS	- Global Positioning System
h	- hour
ha	- hectare
IDW	- Inverse Distance Weighted
INM	- Integrated Nutrient Management
K	- Potassium
KAU	- Kerala Agricultural University
Kg ha^{-1}	- kilogram per hectare
kg m^{-2}	- kilogram per square metre
KSPB	- Kerala State Planning Board
L	- litre
LQI	- Land Quality Index
m	- metre
MDS	- Minimum Data Set
Mg	- Magnesium
Mg ha^{-1}	- Mega gram per hectare
Mg kg^{-1}	- milligram per kilogram
Mg m^{-3}	- Mega gram per cubic metre
Mha	- million hectare
ml	- millilitre
mm	- millimeter
Max.	- Maximum
Min.	- Minimum
Mn	- Manganese
MWHC	- Maximum Water Holding Capacity
N	- Nitrogen

NI	- Nutrient Index
nm	- nanometer
No.	- Number
OC	- Organic carbon
P	- Phosphorus
Pb	- Lead
PC	- Principal component
PCA	- Principal Component Analysis
PCC	- Pearson Correlation Coefficient
PD	- Particle density
PNP	- *p*-nitrophenyl
r	- correlation coefficient
rpm	- rotation per minute
RSQI	- Relative Soil Quality Index
S	- Sulphur
SD	- Standard deviation
SLUSI	- Soil and Land Use Survey of India
SOC	- Soil Organic Carbon
SQ	- Soil Quality
SQI	- Soil Quality Index
SWC	- Soil and Water Conservation
USDA	- United States Department of Agriculture
viz.	-Namely
Zn	- Zinc

Introduction

INTRODUCTION

The country receives a major portion of rainfall during the monsoon season and majority of the country's population depend mainly on this water for agriculture, hydration and industry. Substantial discrepancy in the intensity and duration of monsoon rains have a consequential impact on the lives of the people in India. The occurrence of very frequent, heavy rainfall, causes flooding. Flooding has also become more common in India under the global warming scenario (Mohapatra and Singh, 2003; Fowler *et al*., 2010). In recent years, several parts of India have experienced devastating flood events. The Mumbai floods of 2005, Uttarakhand flood of 2013 and Chennai flood of 2015 are recent examples of floods that have resulted in unparalleled damage to life and property in India.

The period from June 2018 to August 2018 has seen the worst floods in the state of Kerala since 1924. The State has received abnormally high rainfall of about 2346.6 mm from the first week of June to the third week of August, 2018, an abysmal 42% increment from the normal rainfall of 1649.5 mm. This unprecedented rainfall has resulted in disastrous flooding in all districts of Kerala except in the northern most district, Kasargod.

Floods have adversely affected all the three distinct physiographic zones of the state, namely, the highlands, midlands and the low lands (coastal plains). Wayanad (Kabini basin), Idukki (Periyar basin), Ernakulam and Thrissur (Periyar and Chalakudy basins); Alappuzha and Pathanamthitta (Pamba basin) have been the worst affected districts in the State. Torrential rains have resulted in colossal landslides in the hilly areas and caused severe waterlogging in the lowland areas. A total of 537 landslides have been reported from districts such as Wayanad, Idukki, Malappuram, Kozhikode, Thrissur and Palakkad. Also the entire Kuttanad region lying in Alappuzha, Kottayam and Pathanamthitta districts have been submerged for weeks in 8 to 15 feet high flood water. (Kerala state biodiversity board, 2018).

The devastating flood and associated landslides have adversely affected all aspects of human lives including socioeconomic conditions, transportation, infrastructure, agriculture and livelihood. Around 483 lives were lost in floods and landslides. Besides loss of livestock and property, the floods have also wrought havoc in the agriculture and plantation sectors. Extensive areas of agricultural land and plantation crops have been wiped out due to floods and landslides in the hilly tracts such as Idukki and Wayanad. The floods have detrimentally distressed the lives of 3.14 lakh farmers, through damage to nearly 56,844.44 ha of cropped area and a loss of Rs 1355.68 crore. The most affected crops include paddy, banana, tubers, and spices, about 26,106 ha of paddy and 6,348 ha of banana crops were damaged (GOK, 2018).

Wayanad district was one of the worst affected districts in the northern part of Kerala. This district has faced floods, landslides, landslips and land subsidence. The Kabini river and its four important tributaries, the Panamaram, Manathavady, Bavali and Noolpuzha, drain the entire Wayanad district. Any rise in the water levels of these rivers has resulted in floods in the Wayanad district. Amongst the 4 blocks in the Wayanad district, Panamaram and Mananthavady blocks were heavily affected by floods, whereas, Kalpeta and Sultan Bathery were comparatively less affected (ICAR-CTCRI, 2018).

Soil degradation due to flooding is a serious concern. Soil degradation in India is estimated to be occurring on 147 million hectares of land among which 14 million ha of soil suffer degradation due to flooding annually (Bhattacharyya *et al*., 2015). The flood will deteriorate soil quality by impairing its physical, chemical and biological properties. The surface and subsurface soils from hilly terrains get eroded due to the beating and slaking action of high intensity rainfall and get deposited in the low lying flood plains and valleys. This means that the nutrient rich top soil formed over the decades are completely stripped out, thereby exposing the less fertile rocky base. Floods in the Karnataka state in 2009 caused an estimated loss of 287 million tons of top soil and soil nutrient loss from 10.75 million hectares of farmlands (Ramamurthy *et al*., 2009). Apart from the loss of nutrients from leaching; surface crusting, surface cracking of soils and destruction of flora and fauna have occurred due to the flood. Also, when soil is under water saturated condition for an extended period of time, both soil health and quality are deleteriously affected.

The significance of soil quality lies in achieving sustainable land use and management system, to stabilize productivity and to protect environment. Soil quality has been defined as "the capacity of a specific kind of soil to function with its surroundings, sustain plant and animal productivity, maintain or enhance soil, water and air quality and support human health and habitation" (Karlen *et al*., 1997). Evaluation of soil quality is an indispensable tool in determining the sustainability and environmental impact of agricultural ecosystems (Adeboye *et al*., 2011). Soil quality and sustainability assessment is a basic concept bridging between the protection and utilization aspect of soil.

The disastrous impact of flooding on soil has demanded this study. So the plant nutrition package needs to be revised and site specific management practices should also be recommended on the basis of the altered soil status. Also, an awareness regarding this changed soil status should be generated amongst farmers and they should be trained in the management strategies for the effective implementation of post flood activities in the agricultural sector. Thus a comprehensive study on soil quality of post flood soils will help in developing sustainable crop management strategies in these flood affected areas.

The present study was conducted with the following objectives:

- To assess the soil quality of post flood soils of Mananthavady block in Wayanad district
- To develop maps on soil characters using GIS techniques
- To work out soil quality index (SQI).

Review of literature

2. REVIEW OF LITRETURE

The present study is an attempt to investigate the effect of flooding on the soil quality in the post-flood soils of Mananthavady block of Wayanad district in Kerala and to prepare GIS based thematic maps on soil characters. The relevant literatures pertaining to the present study entitled “Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district” are discussed in this chapter.

2.1. SOIL DEGRADATION

Soils are dynamic, diverse and non-renewable natural resource which is a source of infinite life and it provides ecosystem services for the sustenance of humanity. Soils are formed as a result of combined action of soil forming factors on parent material and it takes approximately 100 to 400 years for developing 1cm thick soil. In recent decades soil degradation has been becoming more and more serious worldwide thus posing a serious threat to agricultural production and terrestrial ecosystem. Sharma and Mandal (2009) defined soil degradation as losing and lowering of soil functions or the decline in the capacity of the soil to produce goods of value to humans.

The major causes of soil degradation include both natural and human-induced. Natural causes include droughts, floods, tsunamis, avalanches, earthquakes, volcanic eruptions, landslides, wildfires and tornadoes. Inappropriate agricultural practices, land clearing and deforestation, improper management of industrial effluents and wastes, over-grazing, careless management of forests, urban sprawl, surface mining, and commercial/ industrial development are the major human induced causes of soil degradation. Water erosion is the most important degradation problem in India, resulting in loss of topsoil and terrain deformation. Soil degradation in India is calculated to be occurring on 147 million hectares (Mha) of land, including 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity, and 7 Mha from a combination of factors (Bhattacharyya *et al*., 2015).

Once these valuable soils are degraded then it is difficult or expensive to restore and improve. Soil quality concept has attained more importance to address increased concerns about environmental quality, sustainability and global climate change. The soil quality assessment is not limited to the crop production only, but also comprises the prevention of environmental and soil degradation as well as the betterment of human and plant health (Bunemann *et al*., 2018).

2.2. EFFECTS OF FLOODING ON SOIL PROPERTIES

When a soil is under water saturated condition for a long period of time, then various changes may take place within the soil which will affect the physical, biological and chemical properties of soil. Flooded soil may experience post flood syndrome, similar to the fallow syndrome, where the land is left unplanted of any crop for the entire season.

2.2.1. Effect of flooding on physical properties of soil

Several studies have disclosed that gaseous exchange between soil and air will be decreased on submergence of soil and within few hours of inundation, microorganisms and plant roots consume all the available oxygen resulting in anaerobic conditions, that will induce number of changes in soil (Kozlowski, 1984; Neatrour *et al*., 2004). Submergence reduces the albedo values of soil due to darkening of soil by water and due to low reflectance of water surfaces. Increasing water content also lower the thermal diffusivity of soil. On submergence, as a result reduced cohesion soil strength will be lowered and thus disintegration of soil aggregates takes place (Ponnamperuma, 1984). The disrupted aggregates may clog the soil pores and destroy the soil structure. The aggregate stability of cultivated soils is more affected by the reduced conditions than that of uncultivated soils (De Campos *et al*., 2009).

2.2.2. Effect of flooding on chemical properties of soil

Ponnamperuma (1984) stated that dilution in the soil solution due to flood lowers the electrical conductance and increases pH in acidic soils whereas it decreases the soil pH in alkaline soils. Reduced state of the flooded soil is shown by lower redox potential. The redox potential of flooded soils decreases rapidly after flooding, attains a minimum within a few days, increases rapidly to a maximum and then decline asymptotically with time. During the first few weeks after flooding, the specific conductance of flooded soils increases, then reaches a peak and later declines to a stable value. Flooding increases cation exchange capacity of acidic soils and decreases that of alkaline soil. The main chemical changes include transformations of nitrogen, accumulation of carbondioxide, reduction of sulphate, iron and manganese.

Microbes which are capable of doing anaerobic respiration will shift to alternative electron acceptor with loss of soil oxygen. As a result of this, reduction of oxygen, nitrogen, sulfur, iron, manganese takes place in soil, which may lead to solubility changes. For example, Fe^{2+} and Mn^{2+} are more soluble and movement of these ions leads to areas with either deficiency or surfeit of Fe and Mn (Vepraskas and Faulkner, 2001). Fe and Mn may become toxic to plant since soluble forms are more available to plants.

Most of the studies have tended to describe that, up on inundation release of large quantity of phosphorous takes place as a result of reduction of iron (Khalid *et al*., 1977; Loeb *et al*., 2008). Nitrogen depletion also occurs as a result of reduction of nitrate into various gaseous forms like nitrogen, nitrous oxide, and nitrogen dioxide (Vepraskas and Faulkner, 2001). Unger *et al*. (2009a) reported that, flood has resulted in decrease in soil nitrate nitrogen and increase in soil ammoniacal nitrogen, soil nitrate nitrogen depletion was 4 times higher for 5 week stagnant flooding than 5 week flowing flood.

Kalshetty *et al*. (2012) carried out an investigation to study the effect of river Krishna flood on soil properties of cultivated areas in Bagalkot district, Karnataka state. The study revealed that, flood has caused the decreasing of soil pH and increasing of electrical conductivity due to deposition of total dissolved solids. The nitrogen content of soil was declining whereas elevated levels of available potassium and available phosphorus was observed after the flood. Swelling of clay minerals on water saturation and subsequent release of fixed potassium along with dissolution of the stored fertilizers within the flood water has caused the increasing of potassium in flooded soil. The secondary nutrients sulphur, calcium and magnesium were also found to be increased in soil after the flood. There was a slight elevation in iron, zinc and copper content and reduction in manganese and boron content in post-flood soil. There are no much changes in texture, bulk density and water holding capacity of the soil after flooding.

Akpoveta *et al*. (2014) reported an increase in electrical conductivity and reduction in organic carbon, pH, total nitrogen, total phosphorus and cation exchange capacity following flooding in alkaline soil of farmlands in Onitsha and Asaba of Nigeria. There was a major decline in potassium and essential micronutrients like manganese and nickel and elevated levels of heavy metals like Pb, Cd and Cu were also recorded.

In wetlands, flooding has caused an increase in total nitrogen and pH by 31.47% and 0.33 unit, respectively and 17.87% and 29.93%, decrease in soil organic carbon and EC respectively. Due to inundation, Fe and Mn contents were increased and Pb content decreased, whereas Zn, Cu and Cr contents remain unchanged (Ou *et al*., 2019).

2.2.3. Effect of flooding on biological properties of soil

Elhottova *et al*. (2002) and Mentzer *et al.* (2006) stated that anoxic condition developing from flooding causes change in soil microbial community structure. Flood affects the soil enzyme activity by altering oxygen concentration, nutrient availability, and microbial community composition. The activity of enzymes degrading cellulose and lignin increases with flooding (Mace *et al*., 2016). Scientists reported the increased activity of dehydrogenase enzyme in flooded soil (Gu *et al*., 2009; Furtak *et al*., 2020).

Unger *et al*. (2009b) conducted a study on effect of flooding on soil microbial biomass under greenhouse and field condition. They have reported that stagnant flooding in field results in decrease in bacteria: fungi ratio and microbial biomass and this change in decrease varies with depth of sampling. The intermittent flooding has resulted an increase of aerobic bacterial biomass. There were decrease in microbial biomass and markers for gram negative and gram positive bacteria, aerobic bacteria, and mycorrhizal fungi under stagnant flooding in greenhouse.

Ou *et al*. (2019) reported that flooding in wetland has caused the significant changes in enzyme activity as decreased urease and invertase activity and increased alkaline phosphatase activity. And there was a shift from total nitrogen to manganese as main governing factor of enzyme activity during post flood period. The composition of microorganisms was less sensitive to flood disturbance than microbial biomass.

2.3. CONCEPT OF SOIL QUALITY

The concept of soil quality (SQ) is not new, it had been started since the 1990's (Warkentin, 1995; Doran and Parkin, 1997; Karlen *et al*., 1997). Each time scientist had come up with slightly different concepts since, the understanding of soil has been increasing day by day. One of the most frequently used and the oldest concepts of soil quality is, it's suitability for various beneficial uses.

Parr *et al*. (1992) advised that soil quality should not be confined to the soil productivity only, it has to become much broader, encircling human and animal health, food safety and quality, and environmental quality. Scientists have highlighted the significance of demonstrating the effects of soil quality on feed and food quality (Hornick, 1992) or how habitat of wide range of biota is affected by soil quality (Warkentin, 1995). According to Arshad and Coen (1992), quality of soils depends most importantly on people along with other factors like climate, landform because human decisions and actions are that eventually decide whether an agricultural production system is sustainable on a given soil.

Modern definitions for soil quality are based on land use, soil management practices, ecosystem and environment interactions and socio-economic factors (Doran and Parkin, 1997). They defined soil quality as the "capacity of a soil to function within its ecosystem boundary to sustain biological productivity, maintain environmental quality and promote plant and animal health". Johnson *et al*. (1997) suggested that, soil quality is a measure of the state of the soil with respective to the necessity of one or more societies and/ or to any human purpose or requirements.

Later Karlen *et al*. (1997) gave a general definition for soil quality as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain biological productivity, maintain or enhance water and air quality, and promote human health". The soil quality concept deviates from conventional agricultural approach focusing more on soil productivity, shifting the focus to a more holistic approach realizing the various roles played by soil in the agroecosystems and natural environment (Karlen *et al*., 1999).

Roming *et al.* (1995) used the terms soil quality and soil health interchangeably since farmers favoured the use of the term soil health and scientists preferred the use of the term soil quality. But in contradiction to this Karlen *et al*. (1997) strongly recommended that soil health and soil quality should not be used interchangeably.

Soil Quality Institute (USDA, 2006), suggested that the quality concept is primarily related to the concept of sustainability of soil use and management. Wang *et al*. (2012) recommended that for practical purposes, soil quality can be used to judge impact on crop yield, erosion, ground and surface water status and quality, food and air quality.

2.3.1. Types of soil quality

Karlen *et al***.** (1997) recognized that soil quality can be observed in two distinct ways; one as an inherent characteristic of a soil which is governed by soil forming processes and second one is condition or health of the soil which is mainly governed by management practices. One of the dominant characteristics of soil quality is the distinguishing between inherent and dynamic soil properties (Carter *et al*., 2004).

Soil has both dynamic and inherent qualities (USDA, 2006). De la Rosa and Sobral (2008) stated that natural ability of soil to function is called inherent soil quality and dynamic soil quality is how soil changes depending on how it is managed. Inherent soil quality is permanent and do not change easily, whereas dynamic soil nature concentrates on the surface 20-30 cm and describes the state of a specific soil due to land use management practices (Karlen *et al*., 2003).

De la Rosa and Sobral (2008) also reported that compound integration of dynamic and static physical chemical, and biological components have to be specified inorder to assess the soil quality.

2.4. ASSESSMENT OF SOIL QUALITY

Researchers have emphasized the importance of investigation on coordinated and multidisciplinary approaches to evaluate soil quality, assessing long-term potential and limitations (inherent soil aspects), and observing the short-term changes (dynamic soil aspects) in regards to sustainable soil use and management (De la Rosa and Sobral, 2008).

Larsen and Pierce (1991) explained five soil functions that may be used as the basis for assessing the soil quality: to hold and release nutrients and other chemicals; to hold and release water to plants, streams, and subsoil; to maintain suitable soil biotic habitats; to promote and sustain root growth; and to respond to management and resist degradation.

Parr *et al*. (1992) stated that diverse physical, chemical and biological properties of a soil are interrelated in composite ways that decide its potential fitness or capacity to produce healthy and nutritious crops. Hence the data on soil physical, chemical and biological properties are essential to assess soil quality.

Variation in soil quality can be measured by assessing suitable indicators and comparing them with desired values, at different time intervals, for a particular use in a selected agro-ecosystem (Arshad and Martin, 2002).

2.4.1. Soil quality indicators

Due to its complexity, direct measurement of soil quality is not possible neither on-farm nor at laboratories. However, it can be assessed by measuring a number of soil physicochemical and biological properties that serves as a quality indicator (Cardoso *et al*., 2013; Zornoza *et al*., 2015). The variation in these indicators are used to decide whether soil quality is, stable, improving or declining with changes in the land use, management, or conservation practices (Bredja *et al*., 2001).

Soil quality indicators are referred to as measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions. Attributes that are most sensitive to management are the most desirable as indicators (Arshad and Martin, 2002). They have also listed the indicators which are suitable for assessing the quality of agricultural soil, which includes soil depth, aggregation, texture, bulk density, infiltration, pH, EC, organic matter, nutrient availability, retention capacity and respiration.

Zornoza *et al*. (2015) stated that, for developing soil quality it is prime to select different indicators such as physical, chemical and biological. Soil pH and organic carbon are the widely used indicators. Integration of all indicators helps to develop soil quality index (SQI). It provides knowledge about soil processes and information.

There is no procedure or technique to delineate soil quality based on universal set of indicators since soil quality assessment is purpose and site specific (Bouma, 2000). Zhanfeng *et al.* (2006) had given the importance of developing soil quality indicators in such a way that they can delineate role of soil in natural and agro-ecosystems: protecting watersheds, promoting plant growth, and preventing water and air pollution, so that we can get useful information on the dynamics and trends of soil quality by observing the changes in soil quality indicators.

Doran and Parkin (1994) listed certain characters of indicators which should be ensured while choosing them, which includes i) incorporate soil physical, chemical and biological properties and processes and serve as basic inputs required for assessment of soil properties or functions which are more hard to measure directly, ii) be relatively convenient under field conditions, so that both specialists and producers can use them to evaluate soil quality, iii) correlate with natural processes in the ecosystem, iv) be responsive to variations in management and climate, and v) be the components of existing soil databases wherever possible.

Andrews *et al*. (2004) also gave the features of soil quality indicators that includes, easy to estimate, scientifically-based, precise, responsive to land use change and management practices, cost-effective, and robust for attaining primary goals.

Adeboye *et al*. (2011) recommended that in tropical agroecosystems, soil total nitrogen, soil organic carbon, and soil microbial biomass carbon and nitrogen can be used as the indicators for determining soil quality. Integrated soil quality index was determined by Gelaw *et al*. (2015) for evaluating agricultural land which was already exhausted by exploitation, degradation, and mismanagement in Ethiopia. The study revealed that, more than 80% of the overall SQI value was accounted by soil organic carbon, total nitrogen, cation exchange capacity, water stable aggregation, total porosity, and microbial biomass carbon.

Pulido *et al*. (2017) conducted a study to select the indicators for assessment of soil quality and degradation in rangelands of Spain. They identified two sets of indicators in which first set as soil quality indicators, which included soil organic matter, available potassium, cation exchange capacity, soil depth, water content at field capacity and thickness of the Ah- horizon. Second set variable chosen as soil degradation indicators included percentage of bare ground cover, and bulk density. Ramos *et al.* (2019) reported the indicators of soil quality related to water erosion resistance which include water infiltration rate, soil cover and organic carbon.

The dominant soil quality indicators at micro and macro farm scale as recommended by Singer and Ewing (2000) include three categories i) physical indicators: passage of air, structural stability, bulk density, particle size distribution, colour, consistence, depth of root limiting layer, clay mineralogy, temperature, hydraulic conductivity, oxygen diffusion rate, penetration resistance, pore conductivity, pore size distribution, soil strength, soil tilth, structural type, total porosity and water holding capacity; ii) chemical indicators: base saturation percent, pH, plant nutrient availability, plant nutrient content, cation exchange capacity, nutrient cycling rates, contaminant concentration, contaminant availability, contaminant mobility, contaminant presence, electrical conductivity, exchangeable sodium percentage, sodium absorption ratio; and iii) biological indicators: organic carbon, oxidizable carbon, microbial biomass carbon, total biomass, potentially mineralizable nitrogen, soil respiration, enzymes (dehydrogenase, arylsulfatase, phophatase), biomass carbon or total organic carbon, substrate utilization microbial community finger printing, , fatty acid analysis and nucleic acid analysis.

2.4.1.1. Physical indicators

Physical attributes provide information related to aeration and hydrologic status of soil, and soil's capacity to resist physical forces connected with splashing raindrops or rapid water entry into soil that contribute to aggregate breakdown, soil dispersion, and erosion. Physical indicators commonly used to evaluate soil function and quality includes bulk density, available water capacity, aggregate stability, infiltration, soil crusts, slaking, soil structure and macropores (USDA, 2006).

Schoenholtz *et al*. (2000) reviewed that, the soil texture is the most basic qualitative soil physical property controlling nutrient, water and oxygen retention, exchange, and uptake whereas soil depth is a quantitative property which affects the amount of resources available to plants per unit area. Regularly used physical indicators of soil are bulk density, particle density, water holding capacity, porosity, aggregate stability, soil texture etc.

Nimmo (2004) reported that because of their straight relation to cohesive forces, aggregate size and stability are also important to the compassing of soil erosion and surface sealing. Nimmo (2004) and Rabot *et al*. (2018), also stated the effect of soil structure and aggregate stability on soil quality which in turn can influence root growth.

The physical soil quality indicators which are suggested by different scientist includes soil depth (Larsen and Pierce, 1991; Arshad and Coen, 1992), soil texture (Doran and Parkin, 1994), soil tilth (Papendick *et al*., 1991), soil bulk density, available water holding capacity, saturated hydraulic conductivity, aggregate stability (Larsen and Pierce, 1991; Arshad and Coen, 1992; Doran and Parkin, 1994; Kay and Grand, 1996), porosity (Powers *et al*., 1998) and soil strength (Powers *et al*.,1998; Burger and Kelting,1998).

Study conducted by do Nascimento *et al*. (2019) revealed that the soil relative density, relative field capacity, structural stability index, S index, plant-available water capacity, bulk density alert value, and least limiting water range can be used as physical indictors for assessment of effect of long term agricultural production system on soil physical quality.

2.4.1.2. Chemical indicators

Soil chemical parameters directly affect the microbiological processes and these actions, along with soil physico-chemical processes decide the capacity of soils to hold, supply and cycle nutrients and the movement and availability of water (Schoenholtz *et al*., 2000).

There are a large number of potential soil attributes and the final selection will depend upon the function under consideration. Attributes include, pH, status of plant nutrients, salinity, cation exchange capacity, concentrations of potentially toxic elements, and possibly the capacity of the soil to buffer against change (Nortcliff, 2002). Among these indicators, soil organic carbon content, pH, electrical conductivity, available P and K, total N, mineral N, cation exchange capacity were proposed more often than all other indicators (Bunemann *et al*., 2018).

Brandao *et al*. (2011) reported that soil quality degradation and the loss of fertile land can be prevented by increasing organic carbon. So he suggested that it can be used as a functional indicator when evaluating the environmental impacts of different land management practices.

Shukla *et al*. (2006) also reported that soil organic carbon plays a significant role in assessing soil quality. Bongiorno *et al*. (2019) suggested the estimation of permanganate oxidizable carbon as the labile carbon fraction in addition to other valuable soil quality indicators during soil quality evaluation since permanganate oxidizable carbon represents soil management labile carbon fraction.

2.4.1.3. Biological indicators

Biological indicators are the integrative indicator of the variation in the biology and biochemistry of soil resulting from environmental factors or external management (Alkorta *et al*., 2003). Soil biology is also a functional indicator of soil quality and elevated levels of soil biota can lower the soil degradation and desertification (Lal, 2015).

Biological attributes are often preferred for short term evaluation since, they are very dynamic exceptionally sensitive to changes in soil conditions. Indicators that might be evaluated includes meso, micro, and macro organisms, respiration rate or other indicators of microbial activity, and more comprehensive characterisation of soil organic matter. Organic matter is a principal indicator of soil quality for the various functions that it has in soils; as an agent of aggregate stabilization, site for carbon sequestration and storage, cation reserve and as an energy resource for heterotrophic biological activity (Arshad and Martin, 2002).

Das and Varma (2010) reported that soil enzymes are continuously playing crucial role for the sustenance of soil ecology and soil health. Changes in enzyme activity occur much sooner than other parameters hence they can be considered as the better indicators of soil health since, thus providing early indications of changes in soil health.

Utobo and Tewari (2014) suggested that soil enzymes are functional soil quality indicators due to their association to soil biology and are fingerprints of past soil management, and relate to soil tillage and structure.

Taylor *et al*. (2002) stated that estimation of soil enzymes helps in two main ways. It can be either as indicators of process diversity and provide information for effective manipulation of the soil system or as indicators of soil quality for analysing better methods and sustainability of particular type of land management.

2.4.2. Concept of minimum data set

According to Carter *et al*. *(*1997), recognizing key soil indicators that are sensitive to soil function permits the establishment of minimum data set (MDS). Such data sets are composed of a minimum number of soil attributes that will give a practical evaluation of one or several soil processes relevant for a specific soil function. Arshad and Martin (2002) suggested that, a minimum number of indicators are required to be estimated to assess changes in soil quality arising from various management systems and those indicators are regarded as the MDS. That is, the MDS for determining soil quality is the set of physical, chemical and biological indicators which shows at least 70% of variability in the total data set at each sampling site (Rezaei *et al.,* 2006).

The first step is choosing the suitable soil quality indicators to effectively observe critical soil functions as decided by the particular management goals for which an assessment is being made. These indicators jointly form a minimum data set that can be used to evaluate the performance of the critical soil functions related to each management goal (Sharma and Mandal, 2009).

Lima *et al*. (2013) stated that expert opinion, statistical procedures, or a combination of both can be used to obtain MDS. The often used statistical method to decide the MDS is Principal Component Analysis (PCA) (Nosrati, 2013; Askari and Holden, 2015). On the other hand, some scientists have described some of the failures when using PCA to identify a MDS, for example, in PCA the significance of variables for attaining the prime objective of the SQI and reflecting existing soil condition is not considered (Askari and Holden, 2014; Rossi *et al*., 2009). For eliminating data redundancy and co-linearity other multivariate analyses like multiple regression and Discriminant Analysis (DA) have greater potential (Nosrati, 2013; Bunemann *et al*., 2018).

Li *et al*. (2005) conducted a study to assess the soil quality, in E-Zhou City, China and they identified minimum data set of 13 indicators out of 32 soil parameters by using expert opinion. Also the weight of identified indicators was calculated by using Analytical Hierarchy Process (AHP).

Joseph (2014) used the PCA for selecting MDS while doing quality assessment of pokkali soil under different land uses. The identified MDS includes EC, pH, available water, bulk density, fine sand per cent, silt per cent, aggregate stability, available Mg, available S, available Mn, base saturation, organic carbon and microbial biomass carbon.

Lima *et al*. (2013) have also shown that a few attributes, that is a minimum data set of eight (soil organic matter, clay content, earthworms, friability, mean weight diameter, soil colour, organic matter) out of the 29 indicators or just four indicators as chosen by farmers, have given sufficient management information on soil quality variation among the management systems.

Silt, dehydrogenase activity, and Mn were selected as composite of the most sensitive indicators for evaluating soil quality under erosional status and land use by using backward-mode DA (Nosrati, 2013).

Sharma *et al*. (2013) identified two sets of minimum data set for the assessment of soil quality under rain-fed pearl millet – mung bean system and rain-fed pearl millet system. They selected available N, Zn, Ca, K, pH and dehydrogenase assay as the MDS for rain fed pearl millet-mung bean system and available N, Mn, exchangeable Mg, EC, dehydrogenase activity, microbial biomass carbon and bulk density as the MDS for rain fed pearl millet system.

Total nitrogen, magnesium, carbon nitrogen ratio, aggregate size distribution, penetration resistance, bulk density, and soil respiration were selected as the MDS out of twenty two measured soil properties by using PCA in a study conducted by Askari and Holden (2015) for evaluating current arable management practices on soil quality for temperate maritime soils.

Nehrani *et al*. (2020) applied both PCA and DA to understand the best method of identifying MDS for developing soil quality index in semiarid regions under irrigated and rain-fed agriculture. By using PCA soluble sodium, soil organic carbon, available zinc and geometric mean diameter of soil aggregate were identified as MDS, whereas geometric mean diameter of soil aggregate, soil microbial respiration and Zn were identified as MDS by using DA. He stated that even though DA has resulted in slightly superior SQI, the result from PCA were also strong enough to be reliably used.

Metabolic coefficient, total organic carbon, microbial respiration, nitrogen microbial biomass, and the enzyme activities of urease, amylase and dehydrogenase were identified as the most effective soil quality indicators for evaluating the effect of long term management practices on soil quality index (de Andrade Barbosa *et al*., 2019).

Basak *et al*. (2016) conducted a study to identify key indicators for assessment of soil quality under a rice-based cropping system (rice–potato– sesame) in 3 soil orders. Out of 27 soil parameters, dehydrogenase activity and CEC for Inceptisols, mineral nitrogen and very labile carbon for Alfisols, and organic carbon for Entisols were selected as the key indicator for assessment of soil quality under rice based cropping system. Study also revealed that biological and chemical attributes were more sensitive than physical attributes in indicating variation in soil quality and its influences on system yield in all three soil orders.

2.4.3. Soil quality index

Different methods or procedures to integrate soil quality indicators in to a final soil quality index had been developed as a result of efforts taken to address the challenge assessing soil quality. Such approaches are developed to guide advisors, farmers, and researches to realize soil processes and ecosystem services to manage soils in order to encourage sustainability (Bunemann *et al*., 2018; Palm *et al*., 2007).

Parr *et al*. (1992) proposed soil quality index as SQI = f (SP, P, E, H, ER, BD, FQ, MI) where, SP is soil properties, P the potential productivity, E the environmental factors, H the health (human/animal), ER the erodibility, BD the biological diversity, FQ the food quality/safety and MI the management inputs.

Lima *et al*. (2013) followed the method proposed by Karlen and Stott (1994) to assess the SQI. They have chosen the soil functions related to soil quality, such as accommodating water transfer and absorption, accommodating water entry, supporting plant growth and resisting surface degradation to evaluate the effects of various types of soil management on soil quality. These functions were weighted and integrated according to the following expression:

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

Where qwe is the rating for the soil's ability to accommodate water entry, qwt is the rating for the soil's ability to facilitate water transfer, qrd is the rating for the soil's ability to resist degradation, qspg is the rating for the soil's ability to sustain plant growth and wt is the numerical weight for each soil function.

Andrews *et al*., (2002) demonstrated the soil quality indexing which involves mainly 3 steps, that is, (i) select a minimum data set (MDS) of indicators that best represent soil function, (ii) based on their performance of soil functions, score the

MDS indicators (iii) integrate the indicator scores into a comparative index of soil quality.

Standardized principal component analysis (PCA) of all untransformed data that showed statistically significant differences between management systems using ANOVA were performed by Andrews *et al*. (2002) for selecting the MDS. A subset from large data set can be selected by using PCA. Scientist assumed that PCs receiving high values best represent system attributes. There-fore they selected only the PCs with eigen values ≥1. Then for a particular PC, each variable was given a weight or factor loading that represent its contribution to the PC. Then only the highly weighted variables from each PC were retained for the MDS. Then indicators were transformed using nonlinear scoring method. Using PCA results, the MDS variables for each observation were weighted after transformation. Each PC explained a certain amount (%) of the variation in the total data set. This percentage divided by total percentage of variation explained by all PCs with eigen vectors greater than one, provided the weighting factor for variables chosen under a given PC. The soil quality index (SQI) was then calculated using following formula with an assumption that higher index score meant better soil quality or greater performance of soil functions (Andrews *et al*., 2002).

$$\text{SQI}= \sum_{i}^{n} Wi \times Si$$

Where, W is the PC weighting factor and S is the indicator score

Joseph (2014) and many other researchers (Sharma *et al*., 2011; Wang *et al*., 2012; Armenie *et al*., 2013; Sharma *et al*., 2013; Basak *et al*., 2016; Mishra *et al*., 2017; Buragohain *et al*., 2018) also followed the same method proposed by Andrews *et al*. (2002).

Amacher *et al*. (2007) has developed SQI as an index of forest soil health. In which they have integrated 19 estimated chemical and physical properties of forest soil in to a single index. Here based on literature reviews threshold values were given to the soil attributes. He has also given the interpretation and associated soil index value of soil properties. Then the individual index values for all the measured soil properties are summed to give total SQI for forest soil.

Total SQI = $\sum$ individual soil property index values

Then total SQI is expressed as a percentage of the maximum possible value of the total SQI for the soil properties that are measured. Here the maximum value of the total SQI is 26 if all 19 soil properties are measured.

SQI (%) = (Total SQI / maximum possible total SQI for properties measured) x 100

Study conducted by Vasu *et al.* (2016) to evaluate the crop productivity in semiarid Deccan plateau, India by using soil quality index as a tool revealed that, even though SQI assessed using weighted index by both PCA and expert opinion was highly correlated with crop yield, the SQI estimated using expert opinion weighted index showed better correlation. They also recommended the inclusion of subsurface soil properties along with dynamic surface soil properties for evaluating SQI.

Nehrani *et al*. (2020) conducted a study to select the best scoring and integrating methods for a comprehensive SQI to be applied to agricultural land use in semi-arid regions and the result showed that the best scoring and integrating methods was a linear scoring and additive integration approach.

2.5. SOIL QUALITY ASSESSMENT AND LAND USE MANAGEMENT

Herrick (2000) reported that the soil quality appears to be an ideal indicator of sustainable land management. One of the most important goals of sustainable agriculture and land management is to understand the effect of land use and management practices on soil quality and on its indicators. The degree and the direction of the soil quality change in managed ecosystem depends on climate, land use and soil conditions in which inherent soil properties play a major role (Mandal and Jayaprakash, 2012). De la Rosa and Sobral (2008) reported that the importance of soil quality is to balance productivity and environmental protection and to achieve sustainable land use and management system.

An investigation done by do Nascimento *et al.* (2019) to evaluate the impact of Integrated crop–livestock–forestry and integrated crop–livestock systems on soil physical quality found that forestry component were negatively affected the soil physical quality.

The study conducted by Reis *et al*. (2019) has evaluated the soil quality under different deployment times of no-till and they demonstrated the efficiency of the factorial analysis for choosing the parameters to constitute a minimum data set. The soil physical quality index, constructed from macro porosity, soil resistance to penetration and the compaction degree in the pre consolidation pressure showed sensibility to explain and identify soil physical quality changes with different deployment times of no tillage.

A study conducted by Dagnachew *et al*. (2020) to evaluate the effects of soil and water conservation (SWC) measures on soil quality indicators in Ethiopia revealed that Farm lands with SWC measures had significantly enhanced soil chemical (pH, SOC, TN, C:N ratio, and available phosphorus) and physical (silt and clay fractions, and volumetric soil water content) quality indicators as compared with farmlands without SWC measures.

Using the weighted soil quality index, the evaluation of the impact of shifting cultivation on soil quality, in Wokha district of Nagaland was done by Mishra *et al*. (2017). For preparing MDS principal component analysis (PCA) was used. They have identified the three different soil quality classes which include: high quality (SQIw> 0.70) for two forest soils and land under shifting cultivation, low quality (SQIw <0.50), only to third forest soil, and intermediate quality (0.50 < SQI <0.70) in all other soils. Both depth of the soil and land use has influenced the quality of the studied soil.

The impact of long term soil and nutrient management treatments on soil quality indices under cotton-based production system in rain-fed semi-arid tropical Vertisol were studied and it was found that soil quality indices were in the range of 1.46 to 2.10. Conjunctive use of 25 kg P_2O_5 ha^{-1}+50 kg N ha^{-1} through leucaena green biomass maintained significantly higher soil quality index with a value of 2.10 among treatments (Sharma *et al.,* 2011). pH, electrical conductivity, organic carbon, exchangeable magnesium, available potassium, dehydrogenase assay, and microbial biomass carbon are identified as the key soil quality indicators for this study by using PCA.

The addition of bio-fertilizers and bio-compost improved the soil quality in rice fields of Assam and the key parameters that contributed to the improvement of soil quality includes labile carbon fraction, total phosphorus, available potassium, microbial biomass carbon and phosphorus solubilizing bacteria. Moreover SQI also have a positive correlation with rice yield (Buragohain *et al*., 2018).

Wang *et al*. (2012) conducted a work to disclose the impact of land use change on soil quality in the temporal dimension through water stable aggregates, soil organic carbon and enzymes activities and the result revealed that parameters calculated were not straightforward along the temporal dimension, and the cultivated time. And they also found that soil aggregate fractions with size less than 53 µm and greater than 1000 µm were more responsive to land use change, and mainly this two fractions contributed to the total soil organic carbon losses in the croplands.

C/N and C/P ratios and the pH values were identified as useful indicators to evaluate the quality and nutrient status of wetland soil under different land uses while conducting a study on changes of soil organic carbon, nitrogen and phosphorus concentrations under different land uses in marshes of Sanjiang plain (Yang *et al*., 2013).

Declining trend in productivity of rice-wheat rotation in the Indo-Gangetic plain was studied by Bhaduri *et al*. (2014). They revealed that environmental protection was more under non-puddled condition whereas productivity was higher under puddled situation and no-tillage practice always showed higher soil quality index. And SQI was developed using expert-opinion based conceptual framework model.

Aparicio and Cost (2007) identified change in mean weight diameter of soil, S index, and soil cation exchange capacity as the soil quality indicators sensitive to soil changes under continuous cropping system.

Hansen *et al.* (2001) reported that, due to versatile crop rotations, reduced application of synthetic nutrients, and the absence of pesticides, the organic farming leads to higher soil quality with higher microbiological activity than conventional farming.

2.6. NUTRIENT INDEX

The measure of nutrient supplying power of soil to plants which aid to compare the levels of soil fertility of one area with those of another is termed as Nutrient index (NI) value is (Singh *et al.*, 2017).

The three tier system of Parker's nutrient index is used to calculate fertility status of the soil on the basis of percentage of samples in each of the three categories,that is low, medium and high and multiplied by 1, 2 and 3 respectively. Then the index or weighted average is calculated by dividing the sum of the figures by 100. Nutrient Index = $\{(1 \text{ x } A) + (2 \text{ X } B) + (3 \text{ X } C)\}/ TNS$ where A = Number of samples in low category; B = Number of samples in medium category; C = Number of samples in high category and TNS = Total number of samples.

Nutrient index ratings were given as <1.5 as low, 1.5 - 2.5 medium and >2.5 high (Parker *et al.,* 1951). Ramamurthy and Bajaj (1969) later modified the NI ratings in such a way that less than 1.67 for low fertility status, 1.67-2.33 for medium and greater than 2.33 for high.

Based on the nutrient indices of organic carbon available P and available K, the fertility status of the Varahi River basin in Karnataka were grouped into low-medium-low (Ravikumar and Somashekar, 2013). Denis *et al.* (2017) evaluated the nutrient index in respect of soil pH, organic carbon, available P and exchangeable K to evaluate the fertility status of soils of Karnataka and they reported the medium nutrient index for available phosphorus and exchangeable K and low nutrient index for pH and organic carbon.

2.7. LAND QUALITY INDEX

Land quality is the capability of land to carry out particular functions without getting degraded. Food and fibre production, support human and animal habitation, enhance or maintain water quality, carbon sequestration etc. are the specific functions to be done by land. (Beinroth *et al.*, 2001)

Gangadharappa *et al*. (2008) has chosen the SOC stock as the most valuable and reliable land quality indicator in degraded saline sodic agro- ecosystems of Tungabhadra irrigated areas. Erosion, waterlogging, salinity, contamination, etc. are the causes of decline in land quality. SOC, along with some other parameters like available soil water, EC, micro- aggregates and dehydrogenase activity are considered as the important parameters for monitoring the land degradation status by soil erosion (Rajan *et al*., 2010).

Anil Kumar *et al*. (2015) conducted a study on estimation of horizon-wise soil organic carbon stocks to understand its impact on land quality in West coastal and Western Ghats of Karnataka. They have found that SOC stock varied with climatic conditions, thickness of the horizon, type of land use, and bulk density of soil. Dense rubber cultivation and practice of allowing the litter to remain in situ and areas with less erosion recorded the highest SOC stock better land quality. Steep slope, high erosion and light textured soil has resulted the declining of land quality. Finally they have concluded that the, most reliable and differentiating land quality indicator is SOC stock and it can be used individually or along with other indicators for assessing the status of land quality and land degradation.

Increased erosion, reduced organic matter input and increased oxidation as a result of tillage or land use change are three principal mechanisms accounting for decline in SOC stocks under a given agro-climatic condition (Shalima Devi and Anil Kumar, 2009).

According to Natarajan *et al.* (2005), organic carbon, bulk density, and yield obtained from particular land can be considered as indicators of land quality. Mandal *et al.* (2001) evolved a crop specific LQI for sorghum in semiarid tropics of India which was closely related to yield and they recommended that LQI is a function of climate quality index.

2.8. GEOGRAPHIC INFORMATION SYSTEM (GIS) AND SOIL MAPPING

Geographic Information System (GIS) provides a powerful set of tool for collecting, storing, retrieving, transforming, and displaying spatial data from the real world (Burrough and Mc Donnel, 1998). It helps in the management and analysis of the enormous amount of basic data and information. Statistical analysis of spatial and temporal data can be done to generate information products in the form of maps as well as tabular and text reports for land use planning and decision making. There has been remarkable progress in developing GIS based tools for soil resource management at regional scale.

There are different methods for producing digital soil maps based on GIS data layers. Classification, generalized linear models, and regression trees are the methods which are used for fitting quantitative relationships between soil properties and their environment (Mc Bratney *et al.*, 2003).

2.8.1. Spatial variability and soil fertility mapping

In Iran, Sarvi and Matinfar (2019) prepared soil fertility map for the Ardabil plain in Ardabil province using geostatistical Kriging estimator into the geographic information system by ArcGIS software which can be used for planning use of fertilizers for crops. With the help of ArcGis10.1 software and ordinary Kriging interpolation technique Rawal *et al*. (2018) prepared thematic map of different soil parameters in eleven village development committees of Sunsari district of Nepal. Similar way, thematic map of different soil fertility parameters like mechanical composition, pH, soil organic matter, total nitrogen, available phosphorus, available potassium and micro-nutrients zinc and boron were prepared for 25 village development committees of Sarlahi district of Nepal by making use of GPS and GIS. Ordinary kriging interpolation method was used for knowing spatial variability of fertility attributes (Malla *et al*., 2020)

Thakor *et al*. (2014) prepared thematic map showing spatial variability of micronutrients in three zones of Gujarat district by using inverse distance weighted interpolation provided in Arc-GIS 10 software. The resultant thematic map revealed that soils across the north, centre and south districts zone of Gujarat have high amount of available copper, manganese and zinc and optimum amount of boron. Whereas in case of available iron north districts zone of Gujarat have optimum amount while the soils of centre and south districts zone of Gujarat have high amount of iron. By using soil fertility data *viz*, pH, EC, available macro and micronutrients, Prabhavati *et al*. (2015) developed soil fertility map of three micro-watersheds of Karnataka across a climatic gradient in Belgaum district with the help of Arc GIS 10.0. The study brought out the differences in soil fertility parameters across a climatic gradient within a district. The influence was best seen for parameters like pH, OC, available N, K, S and Zn with zones-3 and 8 being similar and zone-9 distinctly different.

Soil fertility mapping using ArcGIS 10.4 was done to identify the fertility constraints in intensively cultivated soils of Bedwatti sub watershed under northern dry zone of Karnataka. Mapping revealed that available N, P, S, Zn and Fe are the major fertility constraints in watershed (Patil *et al*., 2017). In Dharmapuri district of Tamil Nadu, fertility map of available micronutrient has disclosed that zinc deficiency was the most extensive followed by copper and boron (Jegadeeswari *et al.,* 2017). In Hirehallasub-watershed in northern dry zone of Karnataka, Organic carbon, available N, Zn and Fe were identified as the important fertility constraints by mapping using Arc GIS v 10.4 (Patil *et al*., 2018).

Thematic map of different soil fertility parameters has been prepared by Rakesh and Kunal (2019) and Salma *et al*. (2019) for apple orchards of Kinnaur district of Himachal Pradesh and chickpea Growing Soils of Owk Mandal, Kurnool district of Andrapradesh respectively by using GPS and ArcGIS , which can be used as a decision making tool for optimum crop production.

In Kerala, the spatial variation map of different soil fertility parameters and the fertility map showing fertility status of different agro-ecosystems were prepared for Thrissur district. Geostatistical software (ArcGIS 10.2.2) was used to analyze the spatial structure of data and to define the semivariograms. The study showed a strong spatial dependency for potassium and moderate spatial dependency for all other fertility parameters. Thematic maps were generated for each of the soil nutrients using inverse distance weighted interpolation technique in Arc-GIS 10 software and fertility map of different agro ecosystems showed that low fertile soil is mainly concentrated in coconut dominant areas of northern plains (Kavitha, 2017)

2.8.2. Soil quality and Soil degradation mapping

Li *et al*. (2005) started the quantitative evaluation of soil quality and preparation of soil quality map in E-Zhou City, China. With the help of GIS spatial analysis module, the assessment units were created and soil quality indicators and weights were determined by using analytical hierarchy process and experts knowledge. After the calculation of quality index of each assessment unit, the soil quality map of the study area was prepared by using GIS. In Egypt, Ali *et al*. (2015) divided some areas of North-East Nile Delta into different soil quality classes based on physical, chemical, and biological indicators with the help of GIS and remote sensing.

GIS based geostatistical technique was used by Diodato and Ceccarelli (2004) for preparing soil degradation map of southern Italy by considering variables like water erosion, aridity, top-soil depth. Map showing spatial variation of each individual indicator and final soil degradation pattern were prepared. Abdelrahman *et al*. (2016) used both remote sensing and GIS to delineate the eroded areas in the Chamarajanagar district of Karnataka and they also developed thematic map of different fertility parameters to know the current fertility status of the eroded areas. They found that areas which underwent severe erosion were deficient in organic matter and nutrients.

Materials and Methods

3. MATERIALS AND METHODS

An investigation entitled "Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district" was carried out at College of Agriculture, Padannakkad during 2018 to 2020 by conducting survey and collecting samples from flood affected areas of Mananthavady block. The objectives of the study were to assess the soil quality of post-flood soils of Mananthavady block in Wayanad district, to work out soil quality index (SQI) and to develop maps on soil characters using GIS techniques. The methodologies followed in the investigation are detailed in this chapter.

3.1. SURVEY AND COLLECTION OF SAMPLE

3.1.1. Description of study area

The Mananthavady block in Wayand district lies between 11°58'39.66" and 11°41'12.22" N latitude, 75°46'28.99" and 76°7'19.4" E longitude.The Mananthavady block comprises of five grama panchayaths (Vellamunda, Thirunelly, Thondernadu, Edavaka and Thavinhal) and one municipality (Mananthavady) and it spreads over an area of 66681 ha. The block extends over three agro-ecological zones namely AEU 15 (Northern high hills), AEU 20 (Wayanad central plateau) and AEU 21 (Wayand eastern plateau). Among these, Thavinhal, Thondernadu and part of Vellamunda come under AEU 15, Mananthavady, Edavaka and remaining part of Vallamunda, come under AEU 20 and Thirunelly comes under AEU 21.

The northern high hills (AEU 15) have well drained organic matter rich clay soils in hilly terrain and the valleys have imperfectly drained clay soils. The area is dominated by plantations of rubber, pepper and coffee and forest covers major part of it. The climate is tropical humid monsoon type with nearly 4 months dry period (KAU, 2016).

Deep fairly organic matter rich clay soils are present in Wayanad Central Plateau (AEU 20). The plantations of coffee, tea, coconut, arecanut and pepper are mainly seen in uplands of AEU 20, whereas rice and banana are dominant in lowlands. The unit represents highland plateau with low temperature and high rainfall.

The climate is tropical humid monsoon type with dry period around 3 months (KAU, 2016).

Wayanad eastern plateau (AEU 21) indicates the part of highland plateau with less rainfall. Rice, banana, pepper, coffee, tea, coconut, and arecanut are the major crops found here. The climate is tropical subhumid to humid monsoon type with around four months dry period (KAU, 2016).

3.1.2. Collection and preparation of soil samples

A survey of Mananthavady block was undertaken based on a predesigned questionnaire (Appendix I) to identify the flood affected areas in the block and also to collect details related to cropping system, nutrient management practices and visible changes in soil condition due to flooding.

A total of 100 surface soil samples (0-20 cm) were collected from identified flood affected areas of Mananthavady block (Table 1). Geo referencing has been done using a hand held GPS. In addition to this, 200 core samples, 100 samples from 0-15cm and another 100 samples from 15-30cm were also collected from the sampling locations for estimating the bulk density.The soil sampling points of flood affected areas of Mananthavady block are also depicted in the georeferenced location map of the study area (Fig. 1). The resource map provided by the Soil and Land Use Survey of India (SLUSI) was used as the base map.

The collected soil samples were air dried in the laboratory for one week. Using wooden mortar and pestle dried samples were ground separately and sieved using a 2 mm sieve to separate the coarser fragments. Prepared samples were stored in separate polythene cover for doing further analysis.

Table1. Details on sampling locations in Mananthavady block of Wayanad district

Sl. No.	Panchayath/ Municipality	No. of samples	Sampling point	N latitude (°)	E longitude (°)
1	Mananthavady	19	1	11.816547	76.072544
			2	11.802316	76.063876
			3	11.790023	76.053370
			4	11.820033	76.049315
			5	11.804752	76.047469
			6	11.805956	76.034066
			7	11.818884	76.032107
			8	11.800326	76.021688
			9	11.791199	76.011812
			10	11.803568	76.008566
			11	11.819516	76.016445
			12	11.828622	76.010081
			13	11.813208	75.997985
			14	11.809004	75.976972
			15	11.826864	75.992285
			16	11.842423	75.999411
			17	11.849455	75.987297
			18	11.860682	75.989714
			19	11.855977	75.967131
2	Edavaka	17	20	11.789066	76.035867
			21	11.779654	76.029810
			22	11.772796	76.021499
			23	11.762657	76.013380
			24	11.770512	76.006838
			25	11.779523	76.000267
			26	11.789788	75.994375
			27	11.783873	75.983433
			28	11.768726	75.991781
			29	11.759740	75.982292
			30	11.759154	76.001592
			31	11.771908	75.975647
			32	11.787304	75.967373
			33	11.763000	75.966893
			34	11.775978	75.961262
			35	11.765898	75.945908
			36	11.755264	75.956408

Table 1 continued

Sl. No.	Panchayath/ Municipality	No. of samples	Sampling point	N latitude (°)	E longitude (°)
3	Thirunelly	9	37	11.848735	76.042150
			38	11.868798	76.052516
			39	11.855473	76.083410
			40	11.877186	76.092267
			41	11.901065	76.085662
			42	11.904885	76.056436
			43	11.924115	76.092251
			44	11.930635	76.063127
			45	11.952228	76.094912
4	Thavinhal	20	46	11.883689	75.947799
			47	11.863332	75.945072
			48	11.841894	75.943299
			49	11.832507	75.960567
			50	11.815039	75.948831
			51	11.822233	75.933365
			52	11.799017	75.938326
			53	11.782651	75.933355
			54	11.802463	75.918969
			55	11.795117	75.902890
			56	11.829716	75.915215
			57	11.830034	75.891210
			58	11.808687	75.898254
			59	11.790525	75.883555
			60	11.812732	75.879634
			61	11.831106	75.872248
			62	11.799723	75.862972
			63	11.820609	75.853531
			64	11.837946	75.848907
			65	11.842950	75.830530
5	Thondernadu	17	66	11.749384	75.928791
			67	11.769281	75.914150
			68	11.757060	75.910567
			69	11.763875	75.887466
			70	11.771749	75.861991
			71	11.758188	75.852038
			72	11.755841	75.876073

Table 1 continued

Sl. No.	Panchayath/ Municipality	No. of samples	Sampling point	N latitude (°)	E longitude (°)
			73	11.746953	75.897754
			74	11.735216	75.886649
			75	11.746040	75.866117
			76	11.737177	75.855471
			77	11.726972	75.841261
			78	11.725073	75.869753
			79	11.716273	75.855310
			80	11.713235	75.874453
			81	11.720666	75.888746
			82	11.706590	75.888830
6	Vellamunda	18	83	11.706540	75.912265
			84	11.724508	75.921643
			85	11.730061	75.940869
			86	11.713401	75.930056
			87	11.701582	75.932026
			88	11.712190	75.948961
			89	11.731535	75.958988
			90	11.700771	75.958640
			91	11.718233	75.962085
			92	11.716092	75.971893
			93	11.734023	75.974532
			94	11.719550	75.984553
			95	11.739521	75.991481
			96	11.745044	76.006031
			97	11.731317	75.992944
			98	11.732114	76.005930
			99	11.716326	75.996493
			100	11.729277	76.018460

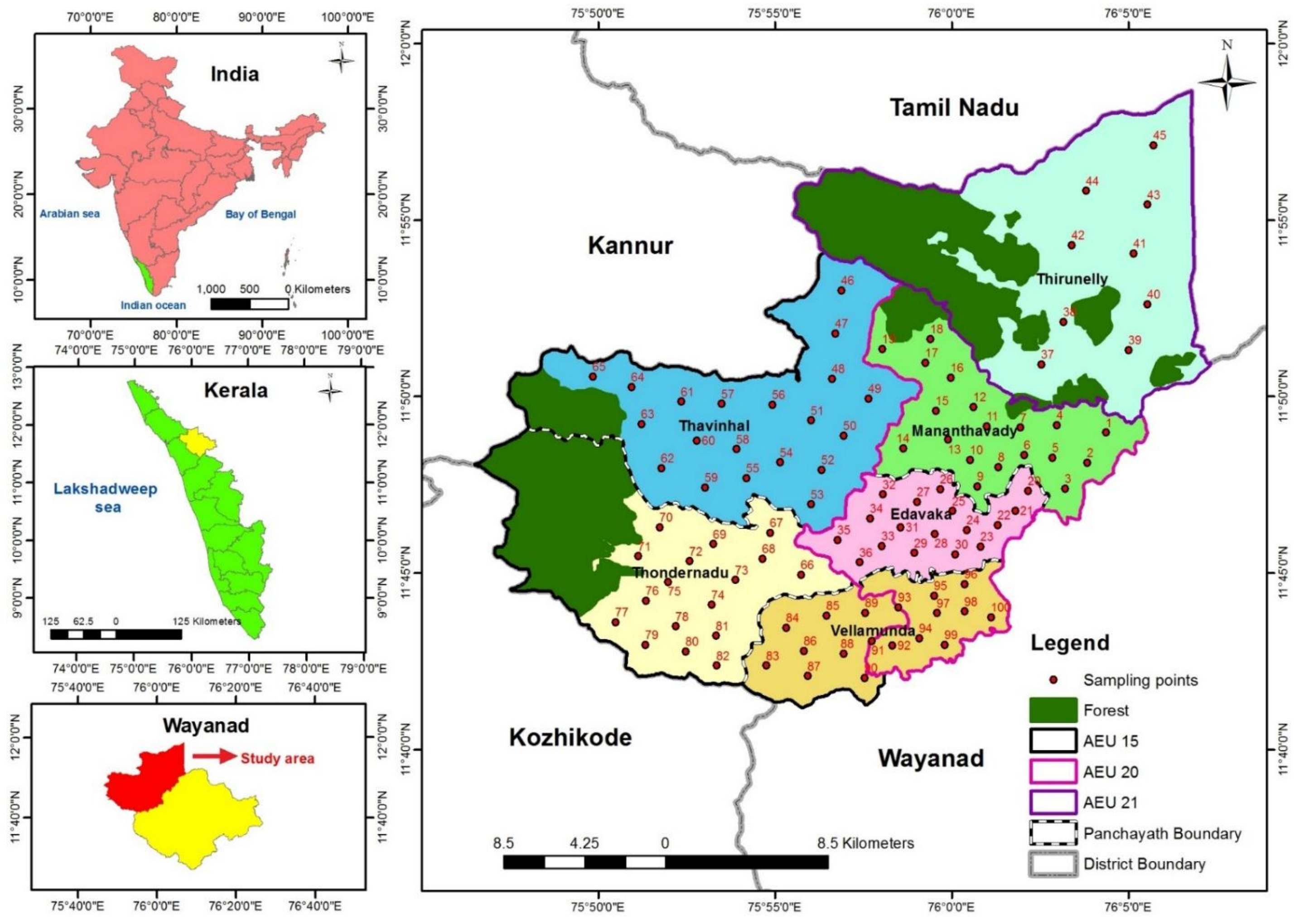

Fig. 1 Location map of study area in Mananthavady block of Wayanad district

3.1.3 Weather data of the area

From RARS, Ambalavayal, the weather data of the area during May 2018 to May 2019, average monthly rainfall and number of rainy days per month for a period of ten years from 2008 to 2017 were collected. The monthly mean minimum temperature, maximum temperature, relative humidity, rainfall and no. of rainy days are represented in Fig. 2. The deviation in rainfall during 2018 compared with the average value for 2008-2017 is given in table 2 and Fig. 3.

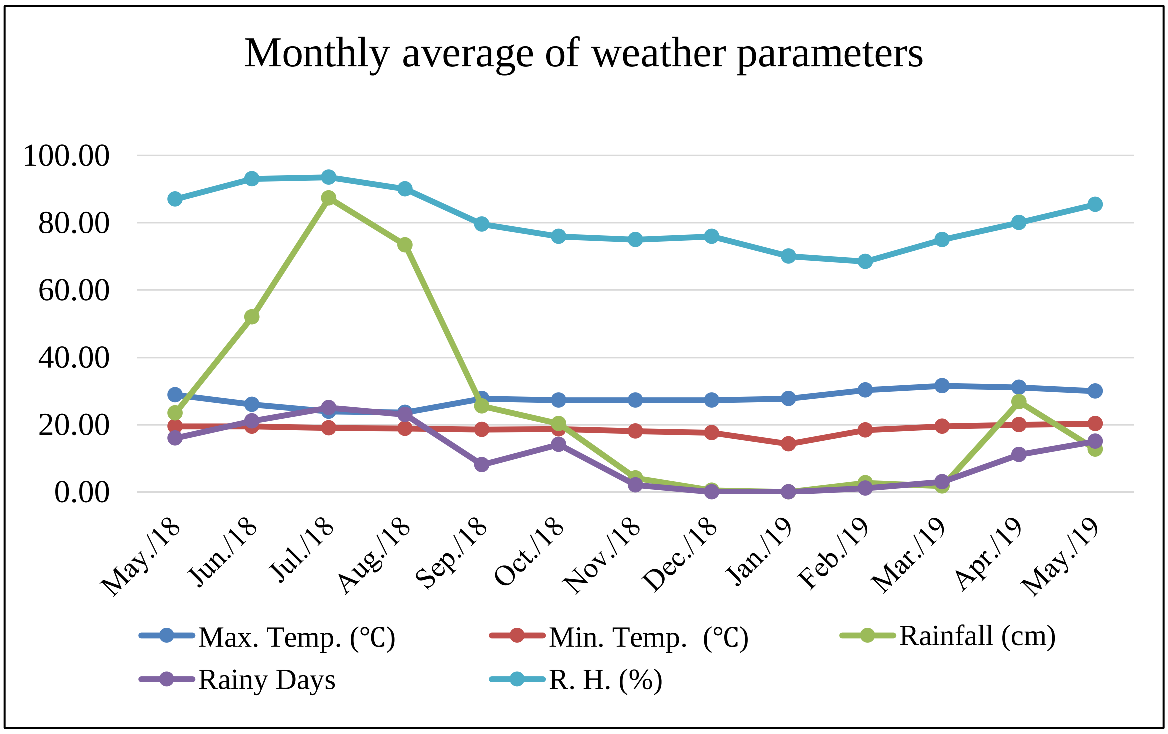

Fig 2. Monthly mean of weather parameters in Mananthavady block (May 2018 to May 2019)

Table 2. Deviation in average monthly rainfall during 2018 from the average monthly rainfall over the last ten years

Month	Average rainfall (cm) (2008-2017)	Rainfall during (cm) 2018	Deviation rainfall (cm)	Average no. of rainy days (2008-2017)	No. of rainy days during 2018	Deviation in no. of rainy days
January	0.992	0	-0.992	0.4	0	-0.4
February	1.196	0.22	-0.976	0.8	0	-0.8
March	6.358	10.48	+4.122	4.3	4	-0.3
April	11.336	12.38	+1.044	8.6	8	-0.6
May	13.812	23.46	+9.648	9.1	16	+6.9
June	32.480	51.91	+19.43	18.2	21	+2.8
July	41.689	87.29	+45.601	22.5	25	+2.5
August	28.25	73.34	+45.09	16.6	23	+6.4
September	16.908	25.46	+8.552	11.8	8	-3.8
October	17.098	20.22	+3.122	9.7	14	+4.3
November	9.49	4.14	-5.350	5.9	2	-3.9
December	2.088	0.4	-1.688	1.6	0	-1.6

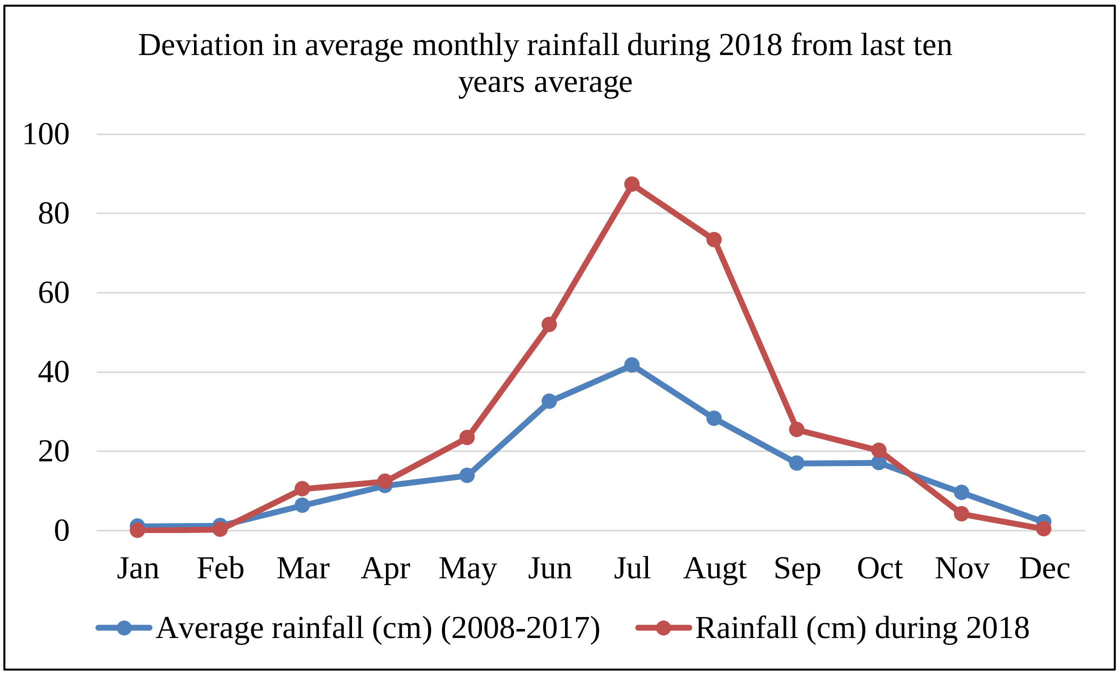

Fig 3. Deviation in average monthly rainfall during 2018 from the average of last ten years

3.2. SOIL ANALYSIS

The soil samples were analysed for physical parameters *viz.*, bulk density, particle density, porosity, soil texture and maximum water holding capacity, chemical parameters *viz.*, pH, EC, exchangeable acidity, organic carbon, available N, P, K, Ca, Mg, S, Fe, Mn, Zn and B, exchangeable Na, exchangeable Al and ECEC, biological parameter *viz.*, acid phosphatase activity.

3.2.1. Chemical Properties

The analytical methods followed for the determination of chemical parameters are given in table 3.

Table 3. Analytical methods followed for chemical characteristics of soil

Sl. No	Parameter	Method	Reference
1	pH	pH meter (1:2.5 soil water ratio)	Jackson (1973)
2	Exchangeable acidity	1N KCl extraction and standard alkali titration	Sarma *et al*. (1987)
3	EC	Conductivity meter(1:2.5 soil water ratio)	Jackson (1973)
4	Organic Carbon	Walkley and Black method	Walkley and Black (1934)
5	Available N	Alkaline permanganate method	Subbaiah and Asija (1956)
6	Available P	Extraction using Bray No. 1 solution and estimation using spectrophotometer	Bray and Kurtz (1945)
7	Available K	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
8	Exchangeable Na	Neutral normal ammonium acetate extraction and estimation using flame photometry	Jackson (1973)
9	Available Ca	Versanate titration method	Hesse (1971)
10	Available Mg	Versanate titration method	Hesse (1971)
11	Available S	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)
12	Available Fe	0.1 N HCl extraction and estimation using Atomic absorption spectroscopy	Sims and Johnson (1991)
13	Available Mn	0.1 N HCl extraction and estimation using Atomic absorption spectroscopy	Sims and Johnson (1991)
14	Available Zn	0.1 N HCl extraction and estimation using Atomic absorption spectroscopy	Emmel *et al*. (1977)
15	Available Cu	0.1 N HCl extraction and estimation using Atomic absorption spectroscopy	Emmel *et al*. (1977)
16	Available B	Hot water extraction and spectrophotometer estimation	Bingham (1982)
17	Exchangeable Al	1N KCl extraction and standard acid titration	Sarma *et al*. (1987)
18	Effective cation exchange capacity	Sum of Exchangeable bases and Exchangeable Al	Sarma *et al*. (1987)

3.2.2. Physical properties

3.2.2.1. Bulk density (Mg m^{-3})

Bulk density of soil was determined by using core sampler method given by Blake *et al* (1965). Undisturbed soil samples were taken by driving a metallic core of known volume into the soil. After drying, weight was noted and using the values of weight and volume, bulk density was calculated.

3.2.2.2. Particle density (Mg m^{-3})

Particle density of soil was determined by Pycnometer method as given by Vadyunina and Korchagina (1986). Soil samples were added to a pre-weighed clean dry pycnometer and weight of pycnometer along with air dried soil samples were noted. After that half of the pycnometer was filled with water and entrapped air was removed. Again weight was noted after making volume to the brim level. After discarding the contents weight of the pycnometer containing only distilled water was noted, and by using these values particle density of soil was estimated.

3.2.2.3. Porosity (%)

Porosity is measured by using bulk density and particle density (Danielson and Sutherland, 1986).

3.2.2.4. Soil texture

Soil texture has been analysed using International pipette method. Hydrogen peroxide was added to 10 g air dried soil and kept it overnight to decompose the organic matter. After this it placed over a water bath and soil was dispersed by adding sodium hexa meta phosphate solution as dispersing agent. Then it was passed through 200 mesh sieve to separate coarse sand fraction. Then suspension was transferred to a 1000 ml cylinder and volume made to the 1L for analyzing silt, clay and fine sand fraction (Robinson, 1922).

3.2.2.5. Thickness of deposition

It was measured qualitatively during the course of sample collection.

3.2.2.6. Maximum water holding capacity (%)

Maximum water holding capacity was determined by the procedure as given by Dakshinamurthi and Gupta (1968). Air dried soil sample was added to a pre weighed keen's cup having filter paper along with it. Placed it in a trough of water to saturate for 24 hours. After saturation took out the cup from trough and allowed it drain out the excess water for half an hour. Weight of cup along with saturated soil was taken and then expanded soil was removed and transferred to a pre weighed dish. And took the weight of keen's cup with residual soil and dish containing expanded soil. Then both keen's cup and dish were placed in oven at 105℃ till constant weight is obtained. After drying, let it to be cool and weighed again. Then from the following equation maximum water holding capacity was calculated.

$$\text{MWHC (\%)} = \frac{\text{Wt. of saturated soil} - \text{Wt. of oven dry soil}}{\text{Wt. of oven dry soil}} \times 100$$

3.2.3. Biological properties

3.2.3.1. Phosphatase activity

Acid phosphatase was determined by the procedure as given by the Tabatabai and Bremer (1969). 0.2 ml of toluene, 4 ml of modified universal buffer and 1 ml of p-nitro phenyl phosphate solution made in same buffer were added to a wide mouth test tube containing one gram of each of the soil samples. Mixed the content by swirling the tubes for few seconds and incubated at 37℃ for 1 hour. After the incubation period 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.5 M NaOH were added to the tubes and the suspension was centrifuged at 3000 rpm. Filtered the suspension and intensity of yellow colour of supernatant was read using the spectrophotometer at 420 nm. The amount of p-nitro phenol content of the filtrate was calculated by using standard graph prepared from different concentration of p- nitro phenol**.**

3.3. SETTING UP OF A MINIMUM DATA SET (MDS) FOR ASSESSMENT OF SOIL QUALITY (SQ)

Principal component analysis was used to set up the minimum data set for the assessment of soil quality. Then only the principal components (PCs) with Eigen values greater than one was examined hence it is based on the assumption that the PCs receiving the higher values can best represent the system attributes. Weight or factor loading received is used to represent the contribution of each variable to the PC. From each PC, the highly weighted variables (within the 10% of the highest factor loading) were only retained. When more than one variable was retained in the PC, their linear correlation was calculated to avoid redundancy. The variables with highest sum of correlation coefficients were selected for the MDS from the well correlated variables in the PC (Andrews *et al.*, 2002).

3.4. FORMULATION OF SOIL QUALITY INDEX

3.4.1. Soil quality index

The soil quality evaluation was done by using the procedure described by Larsen and Pierce, 1994. The variables in the MDS were assigned an appropriate weight. The status of each attribute was grouped into four classes *viz*. Class-I (very good status), Class-II (good status), Class-III (poor status) and Class-IV (very poor) and marks of 4, 3, 2 and 1 were given to each classes respectively (Kundu *et al.*, 2012; Mukherjee and Lal, 2014). Slight modifications were done on the basis of the soil fertility ratings for secondary and micronutrients for Kerala soil. Then soil quality index (SQI) was calculated using following equation,

$$SQI = \sum W_i M_i$$

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

3.4.2. Relative soil quality index

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

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

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

3.5. NUTRIENT INDEX

Nutrient indices at panchayat levels were calculated for soil organic carbon, available nitrogen, available phosphorus and available potassium using the following equation given by Parker *et al*. (1951) for evaluating the soil fertility status of the area.

$$\text{Nutrient index} = \frac{1\text{x } N_l + 2 \text{ x } N_m + 3 \text{ x } N_h}{N_T}$$

Where, N_l = Number of samples in low category

N_m= Number of samples in medium category

N_h = Number of samples in high category

N_T = Total number of samples

The soils were rated based on the nutrient index value as suggested by Ramamurthy and Bajaj (1969).

Table 4. Nutrient index ratings

Sl. No.	Nutrient index	Range	Remarks
1	I	<1.67	Low fertility status
2	II	1.67-2.33	Medium fertility status
3	III	>2.33	High fertility status

3.6. LAND QUALITY INDEX

Based on soil carbon stock, land quality index was calculated. Soil carbon stock was computed using the equation given by Batjes (1996) and land quality index was estimated using the method given by Shalima Devi and Anil Kumar (2006).

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

Table 5. Land quality index ratings

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

3.7. GENERATION OF GIS MAPS

GIS based thematic maps were prepared for soil texture , soil pH, organic carbon, available macronutrients and micro nutrients, soil quality index, land quality index and nutrient index using ArcGIS v 10.3 software following Inverse Distance Weighting method (IDW).

3.8. STATISTICAL ANALYSIS OF THE DATA

Correlations between physical, chemical and biological parameters were calculated in terms of Pearson's Correlation Coefficient (PCC) (Panse and Sukhatme, 1978) using OPSTAT software.

Results

4. RESULTS

A study entitled “Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district” was conducted during 2018-20 to study the influence of flood occurred during 2018 July – August, on soil characteristics and quality. A survey was undertaken and geo-referenced surface soil samples were collected from the study area. Based on a predesigned questionnaire, the details regarding crops grown, nutrient management schedule adopted by farmers, and details on observable changes in soil properties after the flood, were collected. The collected soil samples were analysed for physical, chemical and biological characteristics in the laboratory and soil quality index, nutrient index and land quality index were formulated. The experimental results obtained during the course of the investigation are presented in this chapter.

4.1. DETAILS ON POST FLOOD AREAS COLLECTED THROUGH SURVEY

The flood and associated land slide during August 2018 has caused great damage all over the Mananthavady block. The major rivers Kabani, Korom puzha, Bhavali puzha, Mananthavady puzha, and Puthushery puzha draining through Mananthavady block overflowed and left the area flooded for several days. Mananthavady, Thavinhal, Thondernadu, and Thirunelly were the worst affected regions and in Vellamunda and Edavaka, the extent of severity was less. Areas were inundated for 3-12 days and water level rose to even more than 1.5-2 m in various parts of the block. Deposition of sand, silt and clay with varying depth were found in the area.

The flood and associated land slide during August 2018 has caused great crop loss all over Mananthavady block. Banana, paddy, coffee, and pepper were the worst affected crops. In banana, especially Nendran variety was severely affected. Lakhs of bunched banana were completely lost due to flood. Hundred hectares of paddy field and thousands of coffee plants were completely destroyed. There were severe yield reductions in coffee plant after flood. Farmers reported the increased incidence of quick wilt in pepper, and root rot in banana cultivated in post flood soils in parts of block.

The details on crops, nutrient management practices and size of holdings are provided in table 6. Majority of the farmers was small and marginal farmers. Banana, paddy, coffee, pepper, vegetables, arecanut, coconut, rubber, and tea are the commonly cultivated crops in the area. The farmers were intensively using the commercial fertilizers in their filed along with organic manures like cow dung, poultry manure and various types of compost. Urea, factamphos, diammonium phosphate, rajphos, murate of potash, sulphate of potash and mixed fertilizers were the commonly used NPK fertilizers by farmers. They were also using micronutrient mixture available in market for different crops. Farmers carry out liming of soil twice a year for coconut and banana plantations followed by the application of chemical fertilizers supplying primary nutrients. Majority of the vegetable and pepper farmers relied on organic nutrient sources like cowdung, vermicompost, biogas slurry and green manure for crop nutrition.

Table 6. Details of field survey conducted in Mananthavady block in Wayanad district

Particulars	No. of farmers	Percentage
Crops		
1. Banana	25	25%
2. Coffee	30	30%
3. Paddy	11	11%
4. Coconut	13	13%
5. Arecanut	7	7%
6. Rubber	6	6%
7. Others	8	8%
Nutrient management		
1. INM	34	34%
2. Organic	23	23%
3. Conventional	43	43%
Size of holdings		
1. < 2ha	96	96%
2. > 2ha	4	4%

4.2. ANALYSIS OF SOIL SAMPLES

4. 2.1. Physical attributes

The soil samples were analysed for physical parameters including bulk density, particle density, porosity, soil texture, thickness of deposits and maximum water holding capacity.

4.2.1.1. Bulk density

Bulk density at 15 cm varied between 1.07 and 1.63 Mg m^{-3} in the post flood area of Mananthavady block in Wayanad district with a mean of 1.33 Mg m^{-3}. The lowest and highest mean at panchayath level were observed for Edavaka (1.24 Mg m^{-3}) and Thirunelly (1.41 Mg m^{-3}) respectively. Bulk density at 30 cm varied between 1.00 and 1.70 Mg m^{-3} in the study area with a mean of 1.31 Mg m^{-3}. The lowest and highest mean at panchayath level were observed for Thavinhal (1.24 Mg m^{-3}) and Vellamunda (1.40 Mg m^{-3}) respectively (Table 7). Bulk density at 30 cm showed only slight variation from the values of bulk density at 15 cm.

Table 7. Bulk density at 15 cm and 30 cm in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Bulk density at 15cm depth (Mg m^{-3})		Bulk density at 30 cm depth (Mg m^{-3})	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	1.34 ± 0.14	1.12 - 1.60	1.32 ± 0.12	1.15 - 1.61
Edavaka	1.24 ± 0.11	1.07 - 1.52	1.27 ± 0.13	1.00 - 1.54
Thirunelly	1.41 ± 0.15	1.22 - 1.60	1.39 ± 0.12	1.20 - 1.57
Thavinhal	1.31 ± 0.15	1.10 - 1.59	1.24 ± 0.15	1.05 - 1.53
Thondernadu	1.30 ± 0.06	1.21 - 1.39	1.26 ± 0.08	1.14 - 1.39
Vellamunda	1.40 ± 0.10	1.23 - 1.63	1.40 ± 0.14	1.10 - 1.70
Mananthavady block	1.33 ± 0.13	1.07 - 1.63	1.31 ± 0.14	1.00 - 1.70

4.2.1.2. Particle density

Particle density ranged between 2.10 and 2.63 Mg m^{-3} in the study area with a mean of 2.36 Mg m^{-3}. The lowest and highest mean were recorded in Thavinhal (2.30 Mg m^{-3}) and Mananthavady municipality (2.42 Mg m^{-3}) respectively (Table 8).

4.2.1.3. Porosity

Porosity varied between 26.66 and 54.18 per cent in the study area with a mean of 43.74%. The highest and lowest mean at panchayath level were observed for Edavaka (47.85%) and Thirunelly (40.39%) respectively (Table 8).

Table 8. Particle density and porosity in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Particle density (Mg m^{-3})		Porosity (%)	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	2.42 ± 0.10	2.19 - 2.63	44.55 ± 6.44	26.66 - 54.09
Edavaka	2.39 ± 0.11	2.10 - 2.54	47.85 ± 5.16	34.47 -54.18
Thirunelly	2.37±0.07	2.28 - 2.48	40.39 ± 6.75	31.03 - 48.53
Thavinhal	2.30 ± 0.10	2.13 - 2.53	43.27 ± 5.97	31.97 - 52.73
Thondernadu	2.31 ± 0.11	2.15 - 2.54	43.76 ± 3.49	37.64 - 52.36
Vellamunda	2.38 ± 0.09	2.21 - 2.50	41.19 ± 3.28	33.52 - 46.08
Mananthavdy block	2.36 ± 0.11	2.10 - 2.63	43.74 ± 5.61	26.66 - 54.18

4.3.1.4. Soil particle size distribution and texture

The mean, range and standard deviation of clay, silt and sand content at panchayath level and Mananathavady block level are given in table 9.

Clay content in the soils of Mananthavady block ranged between 5.50 and 68.50 per cent. The mean value of clay content in the post-flood area of Mananthavady block in Wayanad district was observed to be 28.32%. The lowest and highest mean of clay (%) at panchayath level were observed for Edavaka (19.59%) and Thirunelly (33.78%) respectively (Table 9).

Silt content in the study area varied between 8.7 and 50.15 per cent. The mean value of silt content in the post-flood area of Mananthavady block in Wayanad district was observed to be 17.52%. The highest and lowest mean of silt (%) at panchayath level were recorded for Thavinhal (23.31%) and Mananthavady Muncipality (13.53%) and respectively (Table 9).

The lowest and highest mean for sand content at panchayath level were obtained for Thirunelly (47.29%) and Edavaka (63.98%) respectively. Sand content ranged between 15.80 and 80.50 per cent in the study area with a mean of 54.17% (Table 9).

The predominant textural class in all panchayaths was sandy clay loam. Other textural classes observed were clay loam, sandy loam, sandy clay, silty clay loam, clay and loamy sand.

4.2.1.5. Thickness of deposition

Sediment deposits with varying depth and texture were observed in the post flood area of Mananthavady block (Table 10). Sediment deposition was more in Thavinhal, Edavaka, and Thondernadu.

Table 9. Clay, silt, sand content and soil textural classes in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Clay (%)		Silt (%)		Sand (%)		Dominant soil textural class
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Mananthavady	26.11 ± 7.51	10.80 - 37.80	13.53 ± 2.34	10.00 - 17.10	60.36 ± 7.38	50.70 - 77.30	Sandy clay loam
Edavaka	19.59 ± 7.50	5.50 - 29.70	16.43 ± 6.02	8.70 - 28.20	63.98 ± 8.41	42.20 - 80.50	Sandy clay loam
Thirunelly	33.78 ± 19.71	15.80 - 68.50	18.93 ± 5.14	14.60 - 29.30	47.29 ± 19.49	15.80 - 69.60	Sandy clay loam
Thavinhal	28.82 ± 5.52	17.36 - 36.59	23.31 ± 10.64	14.04 - 50.15	47.87 ± 14.95	16.32 - 65.32	Sandy clay loam
Thondernadu	32.04 ± 4.15	24.56 - 39.56	15.89 ± 5.68	10.19 - 29.48	52.06 ± 7.63	36.24 - 62.30	Sandy clay loam
Vellamunda	32.08 ± 4.21	25.63 - 37.56	17.13 ± 5.21	10.09 - 24.64	50.79 ± 8.44	37.80 - 62.13	Sandy clay loam
Mananthavady block	28.32 ± 9.17	5.50 - 68.50	17.52 ± 7.16	8.70 - 50.15	54.17 ± 12.48	15.80 - 80.50	Sandy clay loam

Table 10. Thickness of deposits in the post-flood soils of Mananthavady block in Wayanad district

Thickness of deposits	Panchayath/ Muncipality	Nature of deposits
<5cm	Thirunelly, Vellamunda	Mixture of coarser and finer material
5-10cm	Mananthavady	
>10cm	Thavinhal, Edavaka, Thodernadu	

2.1.6. Maximum water holding capacity

The maximum water holding capacity of the Mananthavady block varied between 32.57 and 64.10 per cent with a mean value of 46.90%. The highest and lowest mean for MWHC at panchayath level were observed for Thondernadu (50.71%) and Mananthavady (43.09%) respectively (Table 11).

Table 11. Maximum water holding capacity in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Maximum water holding capacity (%)	
	Mean ± SD	Range
Mananthavady	43.09 ± 8.78	33.87 - 62.65
Edavaka	45.47 ± 8.27	32.57 - 60.83
Thirunelly	45.93 ± 8.72	37.23 - 59.63
Thavinhal	48.20 ± 6.23	34.76 - 62.83
Thondernadu	50.71 ± 7.59	40.59 - 63.70
Vellamunda	47.75 ± 6.30	37.49 - 64.10
Mananthavdy block	46.90 ± 7.81	32.57 - 64.10

4.2.2. Chemical attributes

The soil samples were analysed in the laboratory for chemical parameters including pH, EC, exchangeable acidity, organic carbon, available nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, boron, exchangeable sodium, exchangeable aluminium, and ECEC. The results obtained are presented below.

4.2.2.1. Soil pH

The mean, range and standard deviation of pH at panchayath level and block level are given in table 12. Soil pH varied between 3.71 and 6.03 with a mean value of 4.86. The lowest and highest mean value of pH was recorded in Thavinhal (4.71) and Thirunelly (5.14) respectively.

4.2.2.2. Electrical conductivity

The mean, range and standard deviation of EC at panchayath level and block level are presented in table 12. EC varied between 0.04 and 0.76 dS m^{-1}. The mean value of EC for the post flood area of Mananthavady block in Wayanad district was 0.13 dS m^{-1}. The mean of EC recorded the highest value for Thavinhal (0.17 dS m^{-1}) and lowest for Mananthavady, Thirunelly, and Vellamunda (0.09 dS m^{-1}).

4.2.2.3. *Exchangeable Acidity*

The mean, range and standard deviation of exchangeable acidity at panchayath level and block level are presented in table 12. The values for exchangeable acidity ranged between 0.55 and 6.96 cmol (p^+) Kg^{-1} in the post-flood soils of Mananthavady block in Wayanad district with a mean of 3.24 cmol (p^+) Kg^{-1}. The lowest and highest mean for exchangeable acidity at panchayath level were obtained for Thirunelly (2.35 cmol (p^+) Kg^{-1}) and Thondernadu (4.85 cmol (p^+) Kg^{-1}) respectively.

Table 12. Soil pH, electrical conductivity and exchangeable acidity in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	pH		EC (dSm^{-1})		Exchangeable acidity (cmol $(p^+)Kg^{-1}$)	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	4.92 ± 0.44	4.06 - 5.50	0.09 ± 0.05	0.04 - 0.26	2.72 ± 0.76	1.40 - 3.92
Edavaka	4.85 ± 0.49	3.71 - 5.64	0.16 ± 0.21	0.06 - 0.76	2.82 ± 1.03	1.27 - 5.03
Thirunelly	5.14 ± 0.57	4.11 - 5.92	0.09 ± 0.06	0.05 - 0.24	2.35 ± 0.67	1.31 - 3.17
Thavinhal	4.71 ± 0.47	3.73 - 5.61	0.17 ± 0.12	0.06 - 0.44	3.27 ± 1.85	0.55 - 6.96
Thondernadu	4.96 ± 0.33	3.95 - 5.12	0.13 ± 0.08	0.05 - 0.28	4.85 ± 0.98	3.30 - 6.92
Vellamunda	5.01 ± 0.34	4.60 - 6.03	0.09 ± 0.04	0.05 - 0.18	3.07 ± 1.48	0.96 - 6.65
Mananthavady block	4.86 ± 0.45	3.71 - 6.03	0.13 ± 0.11	0.04 - 0.76	3.24 ±1.45	0.55 - 6.96

4.2.2.4. Organic carbon

The mean, range and standard deviation of organic carbon at panchayath level and block level are presented in table 13.The highest mean value for organic carbon was obtained for Thondernadu (1.73%) and the lowest mean value was obtained in Thirunelly (0.73%).The values for organic carbon ranged between 0.30 and 3.12 per cent in the post-flood soils of Mananthavady block in Wayanad district with a mean of 1.33%.

4.2.2.5. Available nitrogen

The mean, range and standard deviation of available N at panchayath and block levels are presented in table 13. The mean of available N recorded the highest value for Thondernadu (243.50kg ha^{-1}) and the lowest for Thirunelly (154.01kg ha^{-1}). Available N content varied from 112.90 to 332.42 kg ha^{-1} in the post-flood area of Mananthavady block in Wayanad district. The mean of available N content for the post-flood area of Mananthavdy block in Wayanad district was 204.52 kg ha^{-1}.

Table 13. Organic carbon and available N status in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Organic carbon (%)		Available Nitrogen (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	1.26 ± 0.74	0.42 - 2.64	190.47 ± 43.46	125.44 - 282.24
Edavaka	1.55 ± 0.95	0.30 - 2.82	168.61 ± 33.25	112.90 - 225.79
Thirunelly	0.73 ± 0.28	0.39 - 1.05	154.01 ± 24.52	131.71 - 206.98
Thavinhal	1.13 ± 0.46	0.30 - 2.31	220.41 ± 47.09	130.71 - 301.06
Thondernadu	1.73 ± 0.45	0.90 - 2.67	243.50 ± 27.18	200.70 - 313.60
Vellamunda	1.34 ± 0.69	0.57 - 3.12	224.05 ± 50.31	144.26 - 332.42
Mananthavady block	1.33 ± 0.70	0.30 - 3.12	204.52 ± 49.22	112.90 - 332.42

4.2.2.6. Available phosphorus

The mean, range and standard deviation of available P at panchayath and block levels are given in table 14. The highest and lowest mean were recorded for Mananthavady (45.06 kg ha^{-1}) and Vellamunda (21.76 kg ha^{-1}) respectively. Available P varied between 15.43 and 183.75 kg ha^{-1} in the post-flood area of Mananthavady block in Wayanad district with a mean of 34.01kg ha^{-1}.

4.2.2.7. Available Potassium

The mean, range and standard deviation of available K at panchayath and block levels are represented in table 14. Available K ranged from 36.18 to 737.30 kg ha^{-1}in the study area. The mean of available K was 194.89 kg ha^{-1} in the block. The mean was highest for Thondernadu (251.82kg ha^{-1}) and lowest for Thirunelly (133.38 kg ha^{-1}).

Table 14. Available P and K status in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Available Phosphorus (kg ha^{-1})		Available Potassium (kg ha^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	45.06 ± 35.68	18.01 - 156.73	171.99 ± 106.76	36.18 - 408.24
Edavaka	34.14 ± 20.42	16.37 - 80.33	172.78 ± 187.15	36.74 - 727.78
Thirunelly	27.58 ± 11.99	17.27 - 51.23	133.38 ± 115.19	53.87 - 419.10
Thavinhal	33.24 ± 25.93	17.32 - 125.31	208.47 ± 126.99	64.51 - 509.26
Thondernadu	38.80 ± 47.38	15.85 - 183.75	251.82 ± 195.82	70.90 - 697.42
Vellamunda	21.76 ± 5.86	15.43 - 41.26	201.84 ± 191.14	48.83 - 737.30
Mananthavady block	34.01 ± 29.44	15.43 - 183.75	194.89 ± 159.96	36.18 - 737.30

2.2.8. Available calcium

Available calcium varied between 220 and 2860 mg kg $soil^{-1}$ for the post-flood area of Mananthavady block in Wayanad district. The mean of available calcium for the area was 570.80 mg kg $soil^{-1}$. The lowest mean of 430 mg kg $soil^{-1}$ at panchayath level was observed for Thavinhal and the highest mean of 886.67 mg kg $soil^{-1}$ was obtained for Thirunelly (Table 15).

4.2.2.9. Available magnesium

The mean, range and standard deviation of available magnesium at panchayath level and block level are presented in table 15. The lowest and highest mean value of available magnesium was observed for Thavinhal (200.40 mg kg $soil^{-1}$) and Thirunelly (486.67 mg kg $soil^{-1}$) respectively. Available magnesium ranged between 84 and 1224 mg kg $soil^{-1}$ in the post-flood area with a mean of 276.84 mg kg $soil^{-1}$.

4.2.2.10 Available sulphur

The lowest mean of available S at panchayath level was observed for Thavinhal (1.90 mg kg soil^{-1}) and the highest was observed in Vellamunda (4.18 mg kg soil^{-1}). Available S varied between 0.45 and 8.73 mg kg soil^{-1}in post-flood soils of Mananthavady block in Wayanad district with a mean of 2.95 mg kg soil^{-1} (Table 15).

Table 15. Available Ca, Mg and S in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Available calcium (mg kg soil^{-1})		Available magnesium (mg kg soil^{-1})		Available sulphur (mg kg soil^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ±SD	Range
Mananthavady	574.74 ± 273.16	260-1160	248.84 ± 125.21	96-564	2.96 ± 2.16	0.60-8.73
Edavaka	535.29 ± 167.56	340-880	295.06 ± 119.93	132-504	2.63 ± 1.84	0.76-6.75
Thirunelly	886.67 ± 814.25	260-2860	486.67 ± 404.77	180-1224	1.95 ± 1.65	0.46-5.61
Thavinhal	430.00 ± 176.58	220-1060	200.40 ± 73.06	84-324	1.90 ± 0.99	0.45-3.54
Thondernadu	518.82 ± 227.76	260-1020	244.94 ± 103.84	96-432	3.72 ± 1.66	1.24-7.84
Vellamunda	647.78 ± 269.13	320-1340	299.33 ± 120.53	168-612	4.18 ± 1.46	1.91-6.71
Mananthavady block	570.80 ± 336.63	220-2860	276.84 ± 171.27	84-1224	2.95 ± 1.82	0.45-8.73

4.2.2.11. Available iron

The mean, range and standard deviation at panchayath and block levels are presented in table 16. The highest and lowest means were observed for Mananthavady municipality (117.89 mg kg soil^{-1}) and Vellamunda panchayath (52.59 mg kg soil^{-1}) respectively. Available Fe ranged between 16.48 and 344.80 mg kg soil^{-1} in the post-flood area with a mean of 90.47 mg kg soil^{-1}.

4.2.2.12. Available manganese

The mean of available manganese content recorded the highest value for Mananthavady (71.08 mg kg soil^{-1}) and the lowest for Thirunelly (39.57 mg kg soil^{-1}). Available manganese varied from 6.42 mg kg soil^{-1} to 189.70 mg kg soil^{-1}in the post-flood area of Mananthavady block in Wayanad district. The mean of available manganese content for the study area was 55.55 mg kg soil^{-1} (Table 16).

4.2.2.13. Available Zinc

The mean, range and standard deviation of available zinc at panchayath level and block level are given in table 17. The highest mean value of 8.45 mg kg soil^{-1} was obtained for Mananthavady and the lowest value was observed for Thirunelly (5.47 mg kg soil^{-1}). The results showed that the available zinc content ranged between 1.96 and 28.50 mg kg soil^{-1} for Mananthavady block with a mean of 6.97 mg kg soil^{-1}.

4.2.2.14 Available copper

The highest and lowest mean for available copper content at panchayath level were obtained for Thondernadu (4.71mg kg soil^{-1}) and Mananthavady (0.95 mg kg soil^{-1}) respectively. Available copper content varied between 0.10 and 11.74 mg kg soil^{-1} in the post-flood area of Mananthavady block in Wayanad district with a mean of 3.10 mg kg soil^{-1} (Table 17).

4.2.2.15 Available boron

The status of available boron at panchayath and block levels is presented in table 17. Available boron varied between 0.05 mg kg soil^{-1} and 0.12 mg kg soil^{-1} for the post-flood area of Mananthavady block in Wayanad district. The mean of available boron for the area was 0.08 mg kg soil^{-1}. The lowest mean of 0.07mg kg soil^{-1}at panchayath level was observed for Thirunelly and Vellamunda. The highest mean of 0.10 mg kg soil^{-1}was obtained for Mananthavady.

Table 16. Available Fe and Mn in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Available iron (mg kg soil^{-1})		Available manganese (mg kg soil^{-1})	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	117.89 ± 81.16	16.50 - 344.80	71.08 ± 56.76	12.32 - 189.70
Edavaka	94.87 ± 42.14	34.98 - 183.90	56.50 ± 26.73	14.37 - 112.30
Thirunelly	114.56 ± 30.74	69.76 - 155.70	39.57 ± 30.67	15.67 - 114.60
Thavinhal	102.95 ± 74.74	16.48 - 308.80	41.30 ± 19.53	6.42 - 82.80
Thondernadu	68.11 ± 46.63	19.46 - 220.90	52.43 ± 28.39	10.14 – 130.00
Vellamunda	52.59 ± 39.55	18.69 - 177.90	65.02 ± 42.66	8.56 – 133.00
Mananthavady block	90.47 ± 61.90	16.48 - 344.80	55.55 ± 37.71	6.42 - 189.70

Table 17. Available Zn, Cu and B in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Available zinc (mg kg soil^{-1})		Available copper (mg kg soil^{-1})		Available boron (mg kg soil^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	8.45 ± 3.00	3.62 - 14.55	0.95 ± 0.73	0.19 - 3.27	0.10 ± 0.01	0.08 - 0.11
Edavaka	7.84 ± 3.15	4.67 - 16.50	2.73 ± 3.76	0.10 - 11.74	0.08 ± 0.02	0.05 - 0.12
Thirunelly	5.47 ± 0.86	3.84 - 6.68	2.36 ± 2.21	0.37 - 7.35	0.07 ± 0.01	0.06 - 0.08
Thavinhal	6.91 ± 1.34	4.55 - 9.23	3.96 ± 2.34	0.62 - 8.94	0.09 ± 0.02	0.07 - 0.12
Thondernadu	5.62 ± 1.58	1.96 - 8.10	4.71 ± 0.80	3.35 - 6.36	0.08 ± 0.01	0.06 - 0.10
Vellamunda	6.71 ± 5.79	2.11 - 28.50	3.59 ± 1.69	1.56 - 7.52	0.07 ± 0.01	0.05 - 0.09
Mananthavady block	6.97 ± 3.30	1.96 - 28.50	3.10 ± 2.68	0.10 - 11.74	0.08 ±0.02	0.05 - 0.12

4.2.2.16. Exchangeable sodium

Exchangeable sodium varied from 0.12 cmol (p^+) Kg^{-1} and 0.43 cmol (p^+) Kg^{-1} in the block (Table 18). The mean value of exchangeable sodium was 0.20 cmol (p^+) Kg^{-1} in the area. The mean was highest for Vellamunda (0.25 cmol (p^+) Kg^{-1}) and lowest for Mananthavady (0.16 cmol (p^+) Kg^{-1}).

4.2.2.17. Exchangeable aluminium

Exchangeable Al varied between 0.50 cmol Kg^{-1} and 6.72 cmol Kg^{-1} in the post-flood area of Mananthavady block in Wayanad district and the mean was observed to be 3.05 cmol Kg^{-1}. The mean value at Panchayath level was the highest for Thondernadu (4.65 cmol Kg^{-1}) and lowest for Thirunelly (2.18 cmol Kg^{-1}) (Table 18).

4.2.2.18. Effective cation exchange capacity

The highest mean value at panchayath level was observed for Thirunelly (11.22 cmol (p^+) Kg^{-1}) and the lowest mean value was recorded for Thavinhal (7.53 cmol (p^+) Kg^{-1}). Effective cation exchange capacity varied between 3.91 cmol (p^+) $Kg^{-1}$and 26.86 cmol (p^+) Kg^{-1} in the post-flood area of Mananthavady block in Wayanad district. 8.82 cmol (p^+) Kg^{-1} was the mean value of ECEC for the study area (Table 18).

4.2.3. Biological attributes

The soil samples were analysed in the laboratory for biological parameter,acid phosphatase activity. The results obtained are presented below.

4.2.3.1. Acid phosphatase activity

Acid phosphatase activity ranged between 11.90 and 58.78 µg PNP produced g $soil^{-1}$ h^{-1} in the post-flood area with a mean of 29.00 µg PNP produced g $soil^{-1}$ h^{-1}. The highest and lowest means were observed for Thavinhal (33.07µg PNP produced g $soil^{-1}$ h^{-1}) and Thirunelly (21.40µg PNP produced g $soil^{-1}$ h^{-1}) respectively (Table 19).

Table 18. Exchangeable Na, Al, and ECEC in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Exchangeable Na (cmol(p^+) Kg^{-1})		Exchangeable Al (cmol(p^+) Kg^{-1})		ECEC (cmol (p^+) Kg^{-1})	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	0.16 ± 0.03	0.12 - 0.23	2.54 ± 0.73	1.25 - 3.82	8.02 ± 2.60	5.13 - 14.79
Edavaka	0.20 ± 0.06	0.15 - 0.43	2.63 ± 0.98	1.17 - 4.78	8.35 ± 2.04	5.00 - 11.51
Thirunelly	0.22 ± 0.06	0.12 - 0.32	2.18 ± 0.65	1.16 - 2.97	11.22 ± 7.3	5.62 - 26.8
Thavinhal	0.20 ± 0.03	0.15 - 0.28	3.04 ± 1.78	0.50 - 6.56	7.53 ± 2.37	3.91 - 13.65
Thondernadu	0.21 ± 0.03	0.16 - 0.28	4.65 ± 0.95	3.15 - 6.72	9.98 ± 1.83	6.60 - 13.00
Vellamunda	0.25 ± 0.06	0.19 - 0.41	2.90 ± 1.43	0.91 - 6.35	9.27 ± 3.19	5.56 - 16.75
Mananthavady block	0.20 ± 0.05	0.12 - 0.43	3.05 ± 1.41	0.50 - 6.72	8.82 ± 3.31	3.91 - 26.86

Table 19. Acid phosphatase activity in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	Acid phosphatase activity (µg PNP produced g $soil^{-1}$ h^{-1})	
	Mean ± SD	Range
Mananthavady	30.12 ± 9.88	14.36 - 49.45
Edavaka	30.01 ± 11.26	13.45 - 58.78
Thirunelly	21.40 ± 7.30	11.90 - 31.05
Thavinhal	33.07 ± 11.49	14.35 - 55.45
Thondernadu	29.03 ± 10.24	14.32 - 48.59
Vellamunda	26.10 ± 7.19	12.48 - 37.18
Mananthavady block	29.00 ± 10.21	11.90 - 58.78

4.3. SETTING OF A MINIMUM DATA SET FOR ASSESSMENT OF SOIL QUALITY

For setting up of minimum data set, principal component analysis was used. Twenty three parameters were used which includes, bulk density, particle density, maximum water holding capacity, sand, silt and clay per cent , pH, EC, organic carbon, available primary and secondary nutrients, available micro nutrients, exchangeable aluminium, effective cation exchange capacity and acid phosphatase activity. The PCA resulted eight principal components with eigen value greater than 1, which were selected to obtain a MDS. These eight principle components explained 21.7%, 14%, 10.1%, 7.0%, 6.5%, 5.6%, 4.7% and 4.4% variance respectively (Table 20).

Contribution of a particular variable to a PC is denoted by factor loadings of that variable under that particular PC. Only highly weighted variables within 10% of the highest factor loading were retained in the PC (Wander and Bollero, 1999). Linear correlation between the variables was worked out when more than one variables were retained in a PC. All the non-correlated highly weighted variables under a PC were considered important and retained. On the other hand, if the variables were significantly correlated ($r>0.6$), then the variable with highest factor loading was retained for the MDS and the remaining eliminated (Andrews and Carroll, 2001). The results of PCA are presented in table 20.

In the first PC, only ECEC which has the highest factor loading was retained as no other variable was within 10% of the highest factor loading. In the PC 2, pH with high loading factor was selected. In PC3, silt, organic carbon and sand have the highest loading factor. Due to high correlation between silt and sand, only silt and organic carbon with high loading factor were retained. Available K was selected from PC 4 and from fifth PC both available B and available S were retained since they have high loading factor and they are found to be non- correlated. From the sixth PC, available Fe was selected. In the seventh PC, again available S and available K were selected. Available P and available Zn were retained in eighth principal component. The minimum data set identified thus consisted of ten parameters (Table 21).

Table 20. Results of principal component analysis

Particulars	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigen values	5.000	3.217	2.316	1.599	1.489	1.289	1.079	1.015
% variance	21.7%	14.0%	10.1%	7.0%	6.5%	5.6%	4.7%	4.4%
Cumulative variance	21.7%	35.7%	45.8%	52.7%	59.2%	64.8%	69.5%	73.9%
Eigen vectors								
Bulk density	0.148	0.184	-0.142	0.070	-0.234	0.321	0.164	0.225
Particle density	0.197	0.075	0.236	0.023	-0.331	0.141	0.029	-0.004
Maximum Water holding capacity	-0.318	-0.117	-0.029	0.101	-0.058	0.061	-0.244	0.243
Sand	0.317	-0.010	0.344	0.266	0.016	-0.022	-0.047	0.086
Silt	-0.119	-0.151	-0.379	-0.332	0.076	-0.257	0.034	-0.089
Clay	-0.337	0.131	-0.173	-0.102	-0.080	0.230	0.038	-0.047
Ph	-0.056	0.453	0.095	-0.107	0.152	0.045	0.243	-0.015
EC	-0.081	-0.246	0.178	-0.147	-0.375	-0.237	-0.348	0.018
Organic carbon	-0.165	-0.181	0.370	0.113	0.100	0.287	-0.069	0.001
Available N	-0.246	-0.255	0.009	0.212	0.266	0.158	0.218	-0.021
Available P	0.153	-0.059	0.152	-0.181	-0.055	0.146	0.346	-0.506
Available K	-0.165	-0.114	0.226	-0.376	-0.067	-0.105	0.422	0.159
Available Ca	-0.279	0.349	0.179	-0.028	-0.130	-0.028	0.035	-0.078
Available Mg	-0.281	0.339	0.083	-0.099	-0.182	0.017	-0.173	-0.053
Available S	-0.010	-0.166	-0.011	0.252	-0.397	0.017	0.460	0.299
Available Fe	0.161	-0.021	0.058	-0.320	-0.046	0.421	-0.316	0.242
Available Mn	-0.187	0.056	0.339	0.251	0.115	-0.274	-0.048	0.015
Available Zn	0.002	0.049	0.222	-0.222	0.206	-0.364	0.144	0.495
Available Cu	-0.195	-0.171	-0.070	-0.183	0.056	0.316	0.071	0.315
Available B	0.082	-0.011	0.299	-0.249	0.437	0.230	-0.063	-0.021
Ex. Al	-0.246	-0.316	-0.000	0.219	0.109	0.112	0.048	-0.150
ECEC	-0.371	0.163	0.148	0.071	-0.127	0.062	-0.020	-0.107
Acid phosphatase activity	-0.026	-0.317	0.238	-0.302	-0.283	-0.028	0.011	-0.231

Table 21. MDS of parameters obtained from PCA

PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
ECEC	pH	Percent silt	Available K	Available B	Available Fe	Available S	Available P
		Organic carbon		Available S		Available K	Available Zn

4.4. FORMULATION OF SOIL QUALITY INDEX

4.4.1. Scoring of soil parameters

The identified minimum data set were used for formulating soil quality index. Then the parameters in the MDS were allotted appropriate weights and scores (Table 22). Scoring was done by using method suggested by Kundu *et al*. (2012) and Mukerjee and Lal (2014) with a slight modification based on the soil fertility rating of Kerala soil. Weights were given based on the existing soil condition, agro-climatic condition and cropping pattern (Singh *et al.,* 2017).

4.4.2. Computation of Soil quality index and Relative soil quality index (RSQI)

Weighted SQI was computed after scoring of soil quality indicators. A relative soil quality index was also calculated to study the change in soil quality and samples were rated based on RSQI value.

The mean, range and standard deviation of SQI and RSQI at panchayath and block levels are presented in table 23. RSQI ranged between 43.50% and 86.00% in the post-flood soils of Mananthavady block in Wayanad district with a mean of 64.88%. The highest and lowest mean of SQI and RSQI were obtained for Thondernadu (273.71, 68.43%) and Thirunelly (241.67, 60.42%) respectively.

Table 22. Soil quality indicators, their weights and classes with scores

Soil quality indicators	Weights	Class I with score 4	Class II with score 3	Class III with score 2	Class IV with score 1
Texture Silt %	10	Loam	Clay loam/ Sandy loam/Sandy clay loam/ Silty clay loam	Sandy clay/loamy sand/ Clay	Grit
pH	13	6.5-7.5	6-6.5/7.5-8	5.5-6/8-8.5	<5.5/ >8.5
Organic carbon (%)	15	>1	0.75-1	0.5-0.75	<0.5
Available K (kg ha^{-1})	12	>280	200-280	120-200	<120
Available P (kg ha^{-1})	12	>24	15-24	10-15	<10
Available S (mg kg^{-1})	7	>5.0	2.0-5.0	1.0-2.0	<1.0
Available B (mg kg^{-1})	6	>0.5	0.25-0.5	0.1-0.25	<0.1
Available Fe (mg kg^{-1})	5	>5	2-5	1-2	<1
Available Zn (mg kg^{-1})	5	>1	0.5-1	0.25-0.5	<0.25
ECEC (cmol (p^+) Kg^{-1})	15	>16	10-16	5-10	<5

Table 23. SQI and RSQI in the post-flood soils of Mananthavady block in Wayanad district

Panchayath/ Muncipality	SQI		RSQI (%)	
	Mean ± SD	Range	Mean ± SD	Range
Mananthavady	256.26 ± 25.42	211.00 - 304.00	64.07 ± 6.36	52.75 - 76.00
Edavaka	258.24 ± 37.36	203.00 - 323.00	64.56 ± 9.34	50.75 - 80.75
Thirunelly	241.67 ± 30.49	189.00 - 274.00	60.42 ± 7.62	47.25 - 68.50
Thavinhal	256.70 ± 32.80	174.00 - 299.00	64.18 ± 8.20	43.50 - 74.75
Thondernadu	273.71 ± 19.87	233.00 - 303.00	68.43 ± 4.97	58.25 - 75.75
Vellamunda	262.72 ± 31.36	218.00 - 344.00	65.68 ± 7.84	54.50 - 86.00
Mananthavady block	259.50 ± 30.44	174.00 - 344.00	64.88 ± 7.61	43.50 - 86.00

4.5. NUTRIENT INDEX

Panchayath wise nutrient indices were estimated for organic carbon and available primary nutrients. Nutrient indices for organic carbon were high for Thondernadu (2.71) and low for all other panchayaths. Nutrient indices for available nitrogen were low for the entire post-flood area of Mananthavady block in Wayanad district. Nutrient indices for available phosphorus were high for Mananthavady (2.63), Edavaka (2.53), Thirunelly (2.44), and Thavinhal (2.50) and medium for Thondernadu (2.24) and Vellamunda (2.28). The nutrient indices for available potassium were medium for Mananthavady (1.79), Thavinhal (2.05), Thondernadu (2.12), Vellamunda (1.89) and low for Edavaka (1.59) and Thirunelly (1.44) (Table 24).

Table 24. Nutrient indices at Panchayath levels in Mananthavady block in Wayanad district

Panchayath/ Muncipality	Nutrient index (NI)							
	Organic carbon		Available N		Available P		Available K	
	NI	Rating	NI	Rating	NI	Rating	NI	Rating
Mananthavady	2.21	Medium	1.05	Low	2.63	High	1.79	Medium
Edavaka	2.29	Medium	1.00	Low	2.53	High	1.59	Low
Thirunelly	1.78	Medium	1.00	Low	2.44	High	1.44	Low
Thavinhal	2.00	Medium	1.10	Low	2.50	High	2.05	Medium
Thondernadu	2.71	High	1.06	Low	2.24	Medium	2.12	Medium
Vellamunda	2.33	Medium	1.11	Low	2.28	Medium	1.89	Medium

4.6. LAND QUALITY INDEX

The range of soil organic carbon stock and the mean, range and standard deviation of land quality index at panchayath and block levels are presented in Table 25. The lowest and highest mean of LQI were observed for Thirunelly (1.55 kg m^{-2})

and Thondernadu (3.35 kg m^{-2}) respectively. LQI value varied between 0.59 kg m^{-2} and 6.79 kg m^{-2}. The mean at block was observed to be 2.61 kg m^{-2}.

Table 25. Soil organic carbon stock and LQI in the post-flood area of Mananthavady block in Wayanad district

Panchayath/ Muncipality	SOC stock (Mg ha^{-1})	SOC (kg m^{-2})		LQI
		Mean ± SD	Range	
Mananthavady	7.44 - 53.56	2.47 ± 1.40	0.74 - 5.36	Very low
Edavaka	5.93 - 54.21	2.92 ± 1.88	0.59 - 5.42	Very low
Thirunelly	8.02 - 25.20	1.55 ± 0.60	0.80 - 2.52	Very low
Thavinhal	6.44 - 43.59	2.18 ± 0.85	0.64 - 4.36	Very low
Thondernadu	18.50 - 49.03	3.35 ± 0.80	1.85 - 4.90	Low
Vellamunda	11.71 - 67.86	2.80 ± 1.44	1.17 - 6.79	Very low
Mananthavady block	5.93 - 67.86	2.61 ± 1.35	0.59 - 6.79	Very low

4.7. GENERATION OF GIS MAPS

Using ArcGIS v10.3 software GIS based thematic maps were prepared. Spatial variability in pH, organic carbon, available macro and secondary nutrients, available micronutrients, soil texture, soil quality index and land quality index were mapped. Nutrient indices at panchayath levels for organic carbon and available primary nutrients were also mapped.

4.8. CORRELATION STUDIES

Correlation between analyzed parameters were worked out in terms of Pearson's correlation coefficient. Correlation between physical parameters, between chemical and biological parameters, between physical, chemical and biological parameters were calculated and the results are presented in table 26, 27 and 28.

4.8.1. Correlation between physical parameters

Bulk density at 30 cm showed a significant positive correlation with particle density (0.240^{*}) and bulk density at 15 cm (0.701^{**}). Porosity has a significant positive correlation with particle density (0.272^{**}) and significant negative correlation with bulk density at 15 cm (-0.890^{**}) and bulk density at 30 cm (-0.577^{**}). Water holding capacity is observed to be significantly negatively correlated with particle density (-0.308^{**}), bulk density at 15 cm (-0.259^{**}) and bulk density at 30 cm (-0.276^{**}). Sand content showed significant positive correlation with particle density (0.381^{**}) and bulk density at 30cm (0.210^{*}) and significant negative correlation with water holding capacity (-0.409^{**}). Silt content in soil is observed to be significantly negatively correlated with particle density (-0.320^{**}), bulk density at 15 cm (-0.202^{*}), bulk density at 30 cm (-0.278^{**}) and sand content (-0.687^{**}). Clay content was significantly positively correlated with water holding capacity (0.481^{**}) and showed significant negative correlation with particle density (-0.268^{**}) and sand content (-0.823^{**}) (Table 26).

Table 26. Correlation between physical parameters

Parameters	PD	BD at 15cm	BD at 30cm	Porosity	MWHC	Sand	Silt	Clay
PD	1.000							
BD at 15cm	0.193	1.000						
BD at 30cm	0.240^{*}	0.701^{**}	1.000					
Porosity	0.272^{**}	-0.890^{**}	-0.577^{**}	1.000				
MWHC	-0.308^{**}	-0.259^{**}	-0.276^{**}	0.116	1.000			
Sand	0.381^{**}	0.117	0.210^{*}	0.051	-0.409^{**}	1.000		
Silt	-0.320^{**}	-0.202^{*}	-0.278^{**}	0.052	0.097	-0.687^{**}	1.000	
Clay	-0.268^{**}	-0.001	-0.068	-0.110	0.481^{**}	-0.823^{**}	0.154	1.000

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

4.8.2. Correlation between chemical and biological parameters

Available Ca (0.588^{**}), available Mg (0.504^{**}), and ECEC (0.320^{**}) showed a significant positive correlation with pH whereas exchangeable acidity (-0.418^{**}), EC

(-0.436**), available S (-0.252*) exchangeable Al (-0.402**) and acid phosphatase (-0.406**) showed negative correlation with pH. Exchangeable Al (0.999**) had significant positive correlation with exchangeable acidity. Available K (0.257**), exchangeable Na (0.238*), and acid phosphatase (0.466**) showed significant positive correlation with EC.

Available N (0.435**), available K (0.252*), available Mn (0.298**), available Cu (0.202*) available B (0.232*), exchangeable acidity (0.458**), exchangeable Al (0.458**), ECEC (0.315**) and acid phosphatase (0.310**) were significantly positively correlated with organic carbon. Available Mn (0.281**), available Cu (0.369**), exchangeable acidity (0.630**), exchangeable Al (0.635**), ECEC (0.300**) and exchangeable sodium (0.294**) showed significant positive correlation with available nitrogen whereas available Fe (-0.246*) showed significant negative correlation with available nitrogen. Available P had significant positive correlation with acid phosphatase activity (0.237*) and negative correlation with available Mg (-0.221*) and exchangeable sodium (-0.206*), whereas available K showed significant positive correlation with available Zn (0.240*), available Cu (0.309**), ECEC (0.232*) and acid phosphatase activity (0.420**).

Available Ca had significant positive correlation with available Mg (0.808**), available Mn (0.404**), exchangeable sodium (0.346**) and ECEC (0.794**) and it also had significant negative correlation with available Fe (-0.216*). Whereas available Mn (0.317**), exchangeable sodium (0.381**) and ECEC (0.770**) showed significant positive correlation with available Mg. Available boron (-0.268**) and available sulphur were found to be significantly negatively correlated.

Available Fe had significant negative correlation with available Mn (-0.243*), exchangeable acidity (-0.220*), and ECEC (-0.246*) and has a significant positive correlation with available boron (0.256*). Whereas available Mn showed significant positive correlation with available ECEC (0.455**). Available Zn (0.198*) and available boron were significantly positively correlated and available Cu showed a significant positive correlation with exchangeable sodium (0.351**), exchangeable acidity (0.259**), exchangeable Al (0.263**) and ECEC (0.203*). Available boron had significant negative correlation with exchangeable sodium (-0.420**) and exchangeable sodium showed significant positive correlation with ECEC (0.375^{**}). Exchangeable Al was observed to be significantly positively correlated with exchangeable acidity (0.999^{**}), acid phosphatase (0.350^{**}), and ECEC (0.385^{**}) (Table 27).

4.8.3. Correlation between physical, chemical and biological parameters

Particle density showed significant positive correlation with available Fe (0.197^{*}) and it had a significant negative correlation with available N (-0.359^{**}) available Cu (-0.233^{*}) exchangeable acidity (-0.339^{**}) and exchangeable Al (-0.339^{**}). Bulk density at 15 cm was significantly negatively correlated with exchangeable acidity (-0.276^{**}), EC (-0.216^{*}), organic carbon (-0.237^{*}), available N (-0.257^{**}), available Mn (-0.299^{**}), available Cu (-0.201^{*}), exchangeable Al (-0.269^{**}) and acid phosphatase (-0.207^{*}). Whereas bulk density at 30cm had significant positive correlation with soil pH (0.222^{*}) and significant negative correlation with exchangeable acidity (-0.386^{**}) organic carbon (-0.240^{*}), available N (-0.348^{**}), available K (-0.229^{*}), available Cu (-0.244^{*}), exchangeable Al (-0.372^{**}) and acid phosphatase (-0.314^{**}). Porosity was significantly positively correlated with EC (0.205^{*}), organic carbon (0.248^{*}), available Mn (0.284^{**}), and acid phosphatase (0.251^{*}).

Organic carbon (0.263^{**}), EC (0.227^{*}), available N (0.359^{**}), available Ca (0.245^{*}), exchangeable acidity (0.514^{**}), available Mg (0.315^{**}), available Mn (0.250^{*}), available copper (0.425^{**}), exchangeable Al (0.514^{**}), exchangeable Na (0.378^{**}) and ECEC (0.511^{**}) were positively correlated with water holding capacity, whereas available P (-0.321^{**}) and available B (-0.201^{*}) showed significant negative correlation with hater holding capacity.

Sand content showed significant positive correlation with available P (0.259^{**}) and available B (0.197^{*}) and it also had significant negative correlation with available N (-0.313^{**}), available Ca (-0.327^{**}), available Mg (-0.404^{**}), available Cu (-0.325^{**}), exchangeable acidity (-0.289^{**}), exchangeable Al (-0.289^{**}) exchangeable Na (-0.377^{**}), and ECEC (-0.428^{**}). Silt content showed a significant positive correlation with exchangeable acidity (0.210^{*}) and exchangeable Al (0.203^{*}). Clay content were significantly positively correlated with available N (0.305**), available Ca (0.541**), available Mg (0.588**), available Cu (0.299**), exchangeable acidity (0.229*), exchangeable Al (0.234*), exchangeable Na (0.390**) and ECEC (0.588**) and clay content were negatively correlated with available P (-0.235*) and available Fe (-0.219*) (Table 28).

Table 27. Correlation between chemical and biological parameters

Parameters	pH	EA	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Ex. Na	Ex. Al	ECEC	Acid phosphatase
pH	1.000																		
Ex. Acidity	-0.418**	1.000																	
EC	-0.436**	0.146	1.000																
OC	-0.100	0.458**	0.195	1.000															
N	-0.191	0.630**	0.055	0.435**	1.000														
P	-0.031	-0.049	-0.018	-0.082	-0.147	1.000													
K	0.128	0.170	0.257**	0.252*	0.190	0.016	1.000												
Ca	0.588**	-0.052	0.021	0.161	0.040	-0.127	0.189	1.000											
Mg	0.504**	-0.030	0.027	0.057	-0.079	-0.221*	0.119	0.808**	1.000										
S	-0.252*	0.148	0.111	0.040	0.161	0.016	0.097	-0.096	-0.159	1.000									

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

Table 27 continued

Parameters	pH	EA	EC	OC	N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Ex. Na	Ex. Al	ECEC	Acid phosphatase
Fe	-0.047	-0.220*	-0.004	0.004	-0.246*	0.153	-0.132	-0.216*	-0.088	-0.049	1.000								
Mn	0.148	0.189	0.118	0.298**	0.281**	-0.136	0.112	0.404**	0.317**	0.035	-0.243*	1.000							
Zn	0.095	-0.10	0.016	0.022	-0.081	-0.001	0.240*	0.121	0.031	-0.060	0.035	0.194	1.000						
Cu	-0.088	0.259**	0.134	0.202*	0.369**	-0.046	0.309**	0.009	0.084	0.080	0.074	-0.020	-0.058	1.000					
B	0.094	-0.098	-0.060	0.232*	0.025	0.163	0.119	-0.086	-0.136	-0.268**	0.256*	0.075	0.198*	-0.037	1.000				
Ex. Na	0.056	0.162	0.238*	0.168	0.294**	-0.206*	0.120	0.346**	0.381**	0.184	-0.094	0.058	-0.163	0.351**	-0.420**	1.000			
Ex. Al	-0.402**	0.999**	0.134	0.458**	0.635**	-0.055	0.171	-0.043	-0.025	0.147	-0.229*	0.191	-0.103	0.263**	-0.096	0.165	1.000		
ECEC	0.320**	0.377**	0.109	0.315**	0.300**	-0.184	0.232*	0.794**	0.770**	0.010	-0.246*	0.455**	-0.013	0.203*	-0.139	0.375**	0.385**	1.000	
Acid phosphatase	-0.406**	0.253*	0.466**	0.310**	0.121	0.237*	0.420**	-0.149	-0.111	0.119	0.134	-0.006	0.024	0.050	0.080	-0.005	0.232*	-0.005	1.000

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

Table 28. Correlation between physical, chemical and biological parameters

Parameters	PD	BD at 15cm	BD at 30cm	Porosity	MWHC	Sand	Silt	Clay
pH	0.044	0.114	0.222^{*}	-0.099	-0.162	-0.040	-0.155	0.175
Ex. Acidity	-0.339^{**}	-0.276^{**}	-0.386^{**}	0.115	0.514^{**}	-0.289^{**}	0.210^{*}	0.229^{*}
EC	-0.009	-0.216^{*}	-0.157	0.205^{*}	0.227^{*}	-0.010	0.068	-0.040
OC	0.034	-0.237^{*}	-0.240^{*}	0.248^{*}	0.263^{**}	0.033	-0.184	0.099
N	-0.359^{**}	-0.257^{**}	-0.348^{**}	0.093	0.359^{**}	-0.313^{**}	0.154	0.305^{**}
P	0.162	0.014	-0.024	0.054	-0.321^{**}	0.259^{**}	-0.150	-0.235^{*}
K	-0.052	-0.195	-0.229^{*}	0.168	0.195	-0.189	0.131	0.155
Ca	-0.085	-0.025	0.024	-0.014	0.245^{*}	-0.327^{**}	-0.123	0.541^{**}
Mg	-0.119	-0.041	0.014	-0.016	0.315^{**}	-0.404^{**}	-0.049	0.588^{**}
S	0.110	0.079	0.157	-0.026	0.064	0.035	-0.026	-0.027
Fe	0.197^{*}	0.175	0.134	-0.085	-0.162	0.183	-0.038	-0.219^{*}
Mn	-0.027	-0.299^{**}	-0.140	0.284^{**}	0.247^{*}	0.027	-0.127	0.062
Zn	-0.043	-0.063	-0.149	0.042	-0.016	0.092	-0.029	-0.102
Cu	-0.233^{*}	-0.201^{*}	-0.244^{*}	0.100	0.425^{**}	-0.325^{**}	0.183	0.299^{**}
B	0.084	-0.080	-0.085	0.115	-0.201^{*}	0.197^{*}	-0.186	-0.122
Ex. Na	-0.111	-0.046	-0.073	-0.003	0.378^{**}	-0.378^{**}	0.157	0.390^{**}
Ex. Al	-0.339^{**}	-0.269^{**}	-0.372^{**}	0.107	0.514^{**}	-0.289^{**}	0.203^{*}	0.234^{*}
ECEC	-0.194	-0.156	-0.140	0.063	0.511^{**}	-0.428^{**}	-0.008	0.588^{**}
Acid phosphatase	0.110	-0.207^{*}	-0.314^{**}	0.251^{*}	0.052	-0.001	0.101	-0.077

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

Discussion

5. DISCUSSION

The present study “Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district.” was carried out during the period 2018-20 to evaluate the soil quality of post flood soils Mananthavady block of Wayanad district and to prepare GIS based thematic maps of different soil parameters. The study consisted of survey, collection and characterization of soil sample, development of minimum data set (MDS), formulation of soil quality index (SQI), land quality index (LQI) and nutrient index (NI) and generation of GIS maps. The results obtained from the present investigation are discussed in this chapter.

5.1. ANALYSIS OF SOIL SAMPLES

5.1.1. Physical attributes

The result of physical parameters *viz*., bulk density, particle density, porosity, soil texture, thickness of deposition and maximum water holding capacity are discussed below.

5.1.1.1. Bulk density

Bulk density at 15 cm ranged from 1.07 Mg m^{-3} to 1.63 Mg m^{-3}. Bulk density of 16 % of samples had less than 1.2 Mg m^{-3} whereas 61% of samples lies in the range of 1.2-1.4 Mg m^{-3}, 19% in 1.4 -1.6 Mg m^{-3} range and 4% had bulk density greater than 1.6 Mg m^{-3}(Fig. 4). The amount of organic matter in soils, texture, constituent minerals and porosity were found to be influencing the soil bulk density (Chaudhari *et al*., 2013). The general status of bulk density in the Mananthavady block was found to be decreased with the increase in organic carbon content and this result was in line with findings of Sakin (2012). It was also observed that higher bulk density was present in soils with more sand content. In the present study significant negative correlation between bulk density and silt content ($r=-0.202^{*}$) was observed which is similar to the findings of Chaudari *et al*. (2013). Accumulation of materials such as debris, silt and microscopic organisms that were brought to soil by flood could be the reason for low bulk density and increase in porosity in the flooded areas (Njoku and Okoro, 2015).

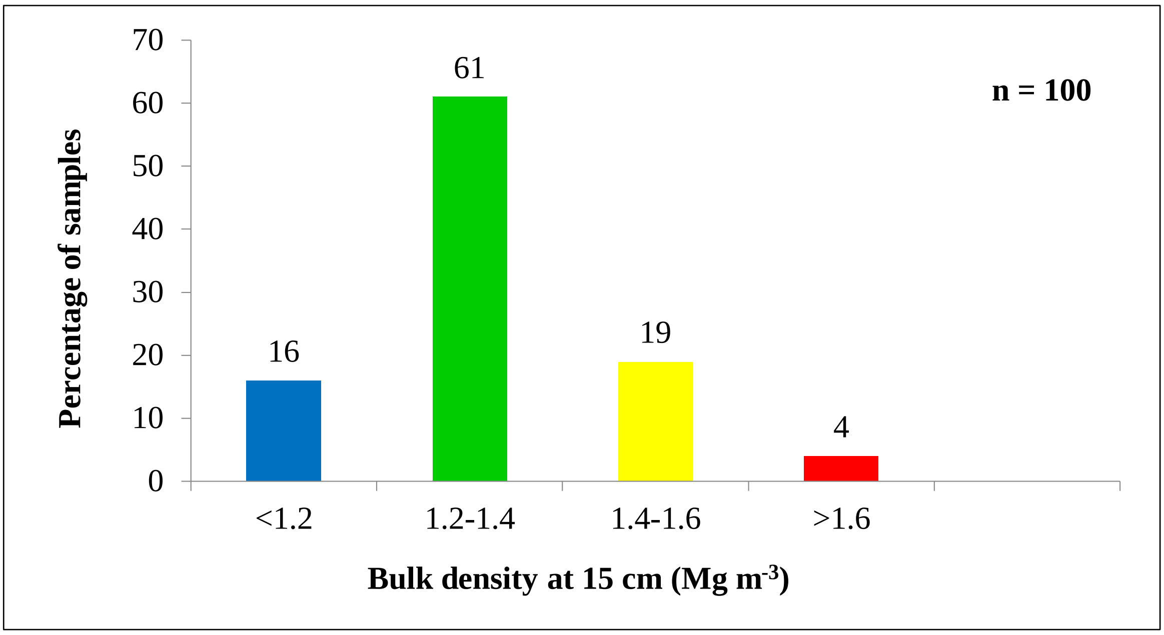

Fig. 4. Frequency distribution of bulk density at 15 cm in the post-flood soils of Mananathavady block in Wayanad district

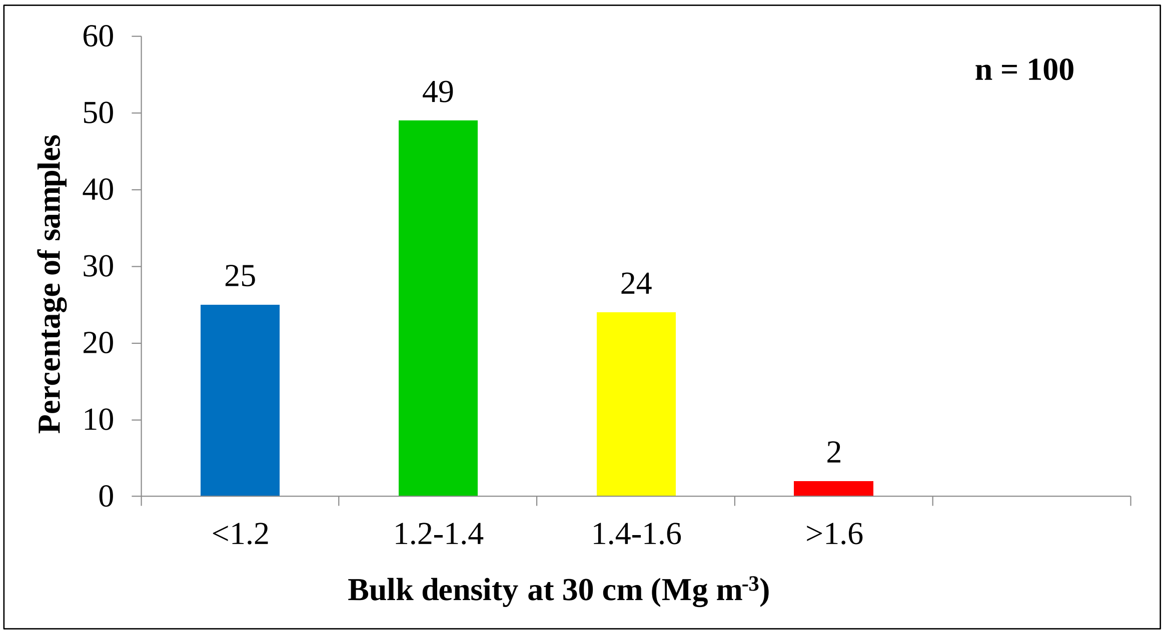

Fig. 5. Frequency distribution of bulk density at 30 cm in the post-flood soils of Mananathavady block in Wayanad district

Bulk density at 30 cm varied between 1.00 Mg m^{-3} and 1.70 Mg m^{-3} in the Mannathavady block. The frequency distribution of bulk density in the study area depicted in Fig. 5 revealed that 25% samples had bulk density less than 1.2 Mg m^{-3} whereas 49% of soil lies in the range of 1.2 –1.4 Mg m^{-3}, 24% in 1.4 -1.6 Mg m^{-3} range and 2% had bulk density greater than 1.6 Mg m^{-3}**.**

5.1.1.2. Particle density

The particle density of post flood soils of Mananthavady block ranged from 2.10 Mg m^{-3} to 2.63 Mg m^{-3}. Particle density showed a positive correlation with sand content. Ruehlmann *et al.* (2006) reported that particle density depends on both the mineral and organic soil components. Particle density values were observed to be lower for samples high in organic carbon content, silt and clay content which is similar to the findings of Ruehlmann *et al.* (2006) who observed that with increase in organic matter content in soil, the particle density tends to decrease. Silt and clay content were negatively correlated with particle density. About 10 % of soil samples had a particle density less than 2.2 Mg m^{-3}, 50 % in the range of 2.2 Mg m^{-3} to 2.4 Mg m^{-3}, 39% in the range of 2.4 Mg $m^{-3}$and 2.6 Mg m^{-3} and 1% had greater than 2.6 Mg m^{-3} (Fig. 6).

5.1.1.3. Porosity

Porosity ranged between 26.66 and 54.18 per cent in the study area. Porosity was positively correlated with organic carbon content and particle density and negatively correlated with bulk density. Higher the bulk density lower will be porosity (Chaudhari *et al.,* 2013). Li and Shao (2006) also reported that porosity was positively correlated with soil organic matter and negatively correlated with bulk density. For 85 per cent of soil samples, soil porosity was in the range of 30 to 50 per cent whereas 14 per cent of samples had porosity in between the range 50 to 70 per cent and one per cent samples had porosity less than 30 per cent (Fig.7).

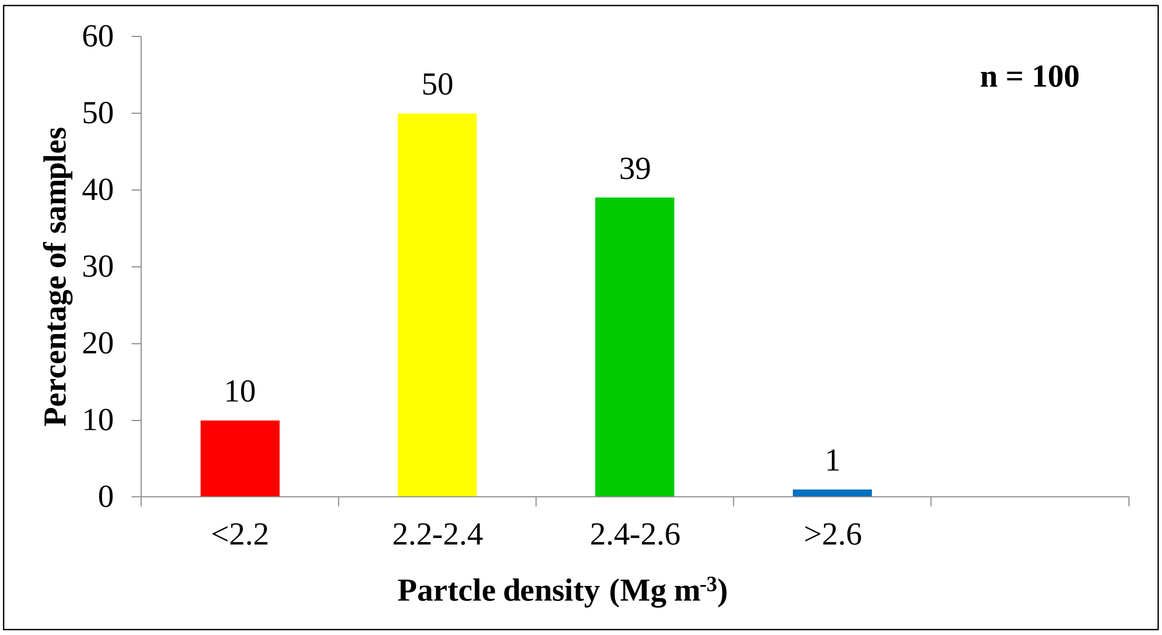

Fig. 6. Frequency distribution of particle density in the post-flood soils of Mananathavady block in Wayanad district

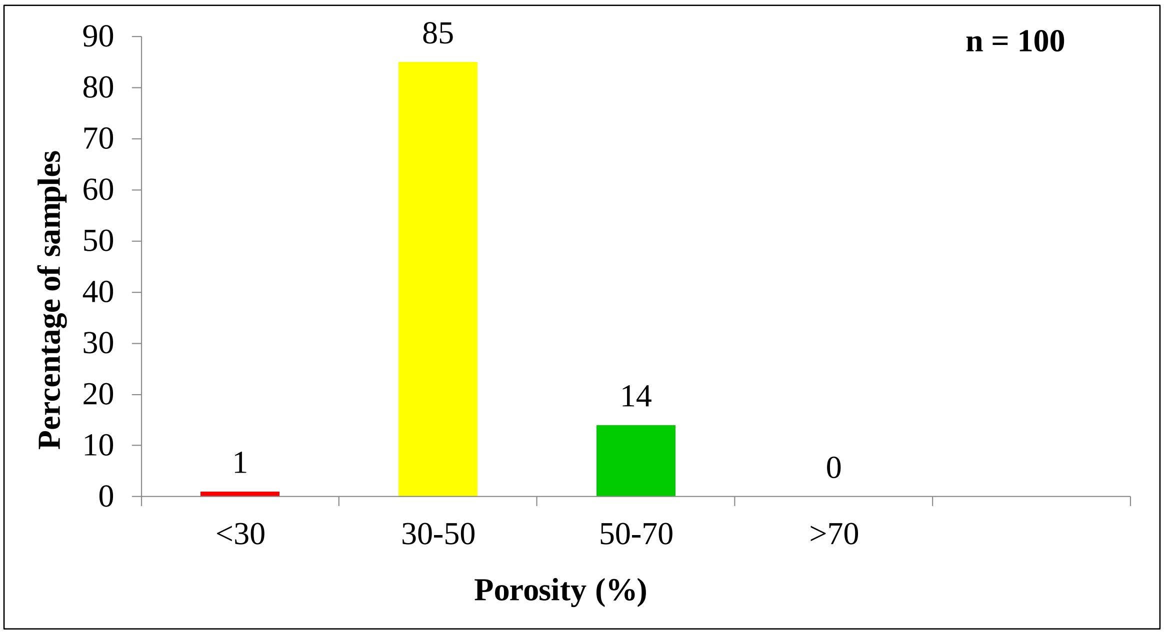

Fig.7. Frequency distribution of porosity in the post-flood soils of Mananathavady block in Wayanad district

5.1.1.4. Soil texture

Sand, silt and clay content exhibited wide variations in the soils of Mananthavady block. Sand content varied between 15.80% and 80.50%. Silt content varied between 8.70% and 50.15% and clay content between 5.50% and 68.50%. Sandy clay loam was the predominant soil textural class observed (60%) in Mananathavady block (Fig 8), followed by clay loam (17%) and sandy loam (14%). Spatial distribution of soil texture is shown in Fig. 9.

5.1.1.5. Thickness of deposition

Sediment deposition is an important part of erosion process and the deposition occurs when the sediment load exceeds the sediment transportation capacity (Polyakov and Nearing, 2003). Deposition of sediments with varying depth and texture was found in Mananthavady block in which more deposition was found in Mananthavady, Edavaka, Thavinhal and Thondernadu. Fine particles are easy to carry away than coarse particles as they have low settling speed (Asadi *et al*., 2011).

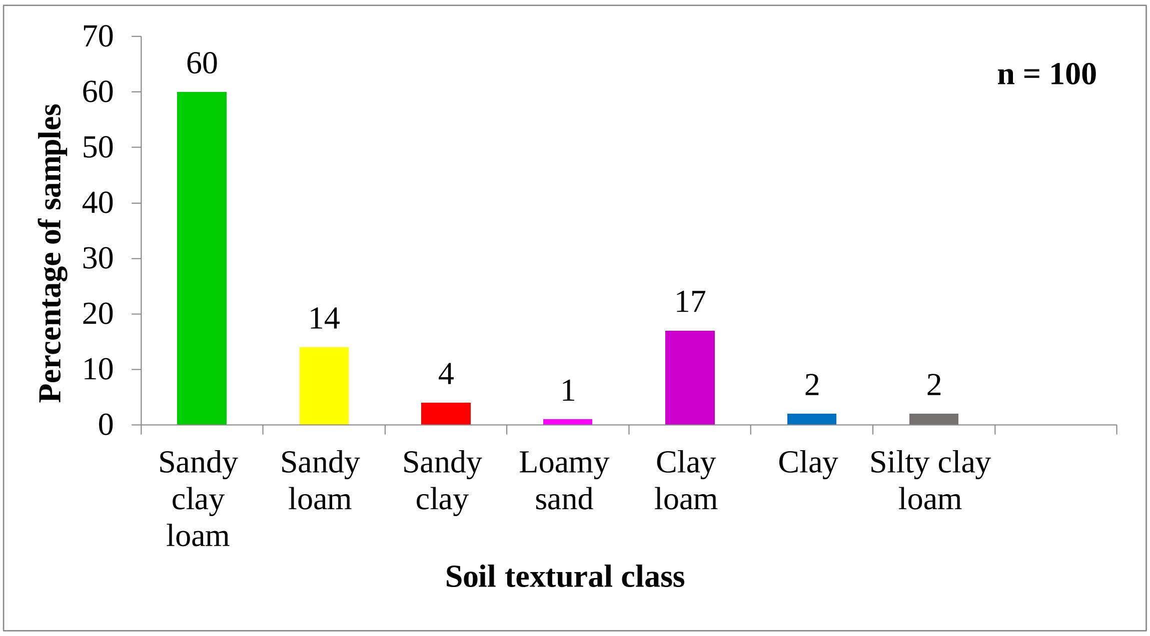

Fig. 8. Frequency distribution of soil textural classes in the post-flood soils of Mananthavady block in Wayanad district

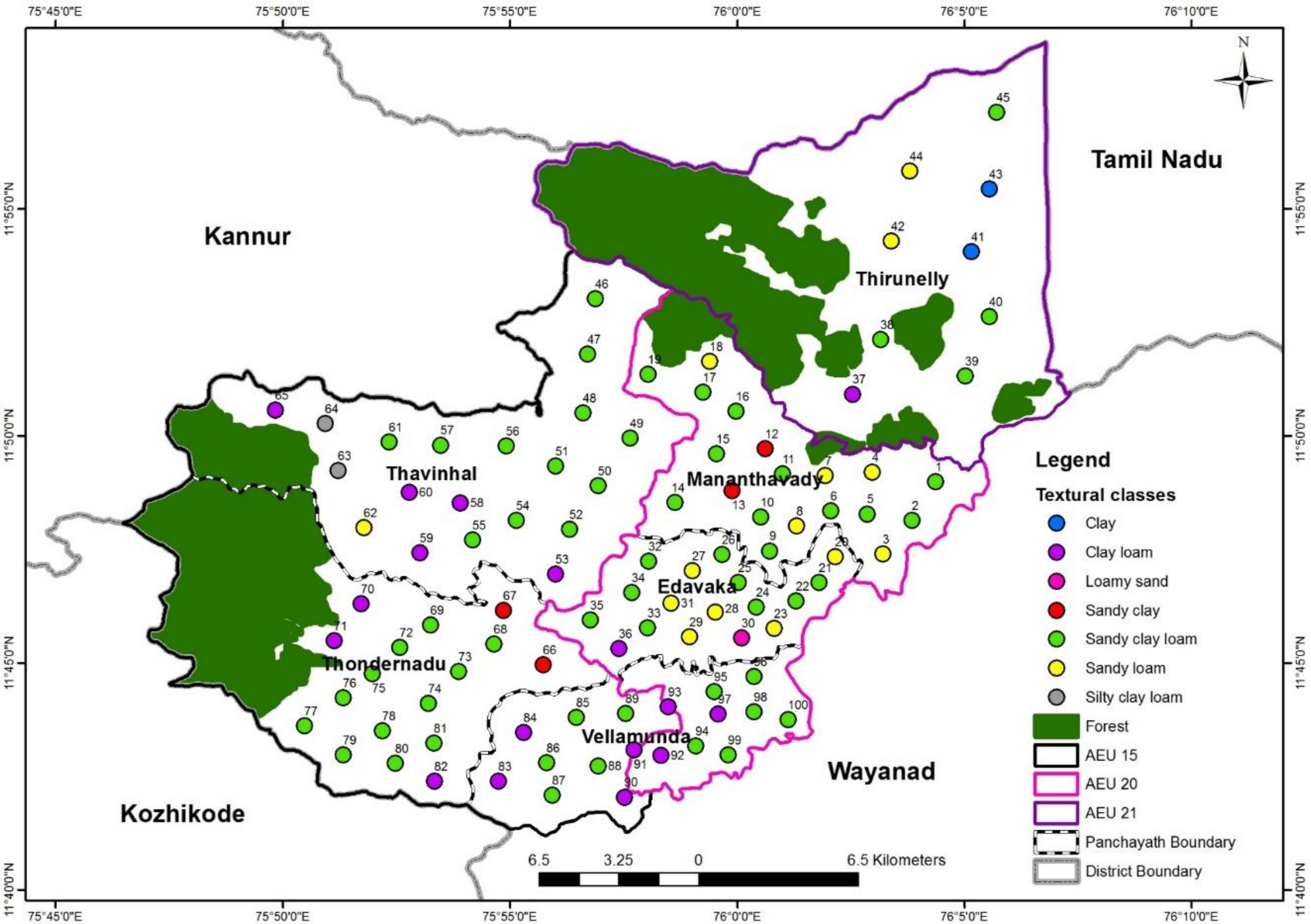

Fig. 9. Spatial distribution of textural classes in the post-flood soils of Mananthavady block in Wayanad district

5.1.1.6. Maximum water holding capacity

Maximum water holding capacity varied between 32.57% (Edavaka) and 64.10% (Vellamunda) for the post-flood soils of Mananathavady block in Wayanad district. Maximum water holding capacity of majority of samples (70%) ranges between 30-50 % and 30% lies between 50-70% (Fig. 10). Maximum water holding capacity in the study area was found to be increasing with increase in clay and organic carbon content and decreasing with increase in sand content. This result was in line with findings of Libohova *et a*l. (2018) who reported that on an average, 4.5% to 5.1% volume increase in available water when soil organic matter in soil increases from 0% to 3% depending on the texture and clay mineralogy. The lowest water holding capacity of 32.57% recorded from Edavaka where least organic carbon content (0.3%) and clay content (5.5%) and high sand content (80.5%) were observed and soil texture was loamy sand.

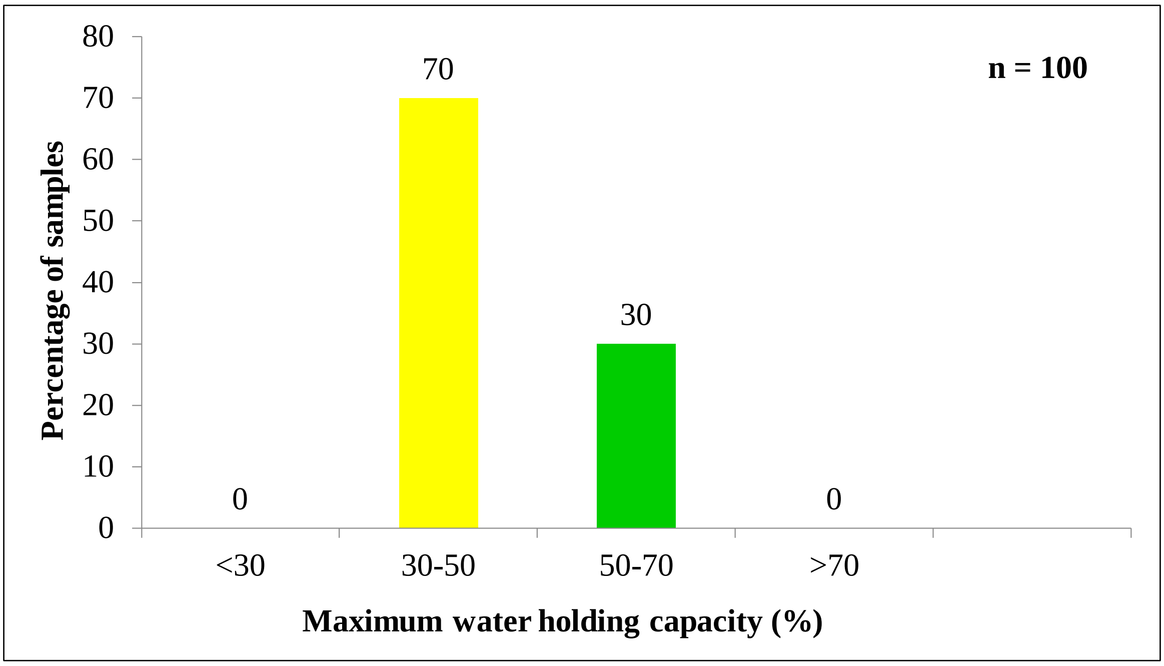

Fig. 10. Frequency distribution of water holding capacity in the post-flood soils of Mananthavady block in Wayanad district

5.1.2. Chemical parameters

5.1.2.1. Soil pH

The present study revealed that the soils of Mananthavady block were extremely acidic to slightly acid with overall pH ranging from 3.71 to 6.03. From the frequency distribution chart it is observed that 20 % soil samples were extremely acidic, 47% of soils very strongly acidic, 25% strongly acidic, 7% moderately acidic and 1% slightly acidic (Fig. 11). On the contrary, 31 per cent of samples were extremely acidic, 29.00 per cent very strongly acidic, 22 per cent strongly acidic and 18% had moderately acidic pH in the pre flood scenario (KSPB, 2013). Spatial distribution of soil pH is depicted in Fig. 12.

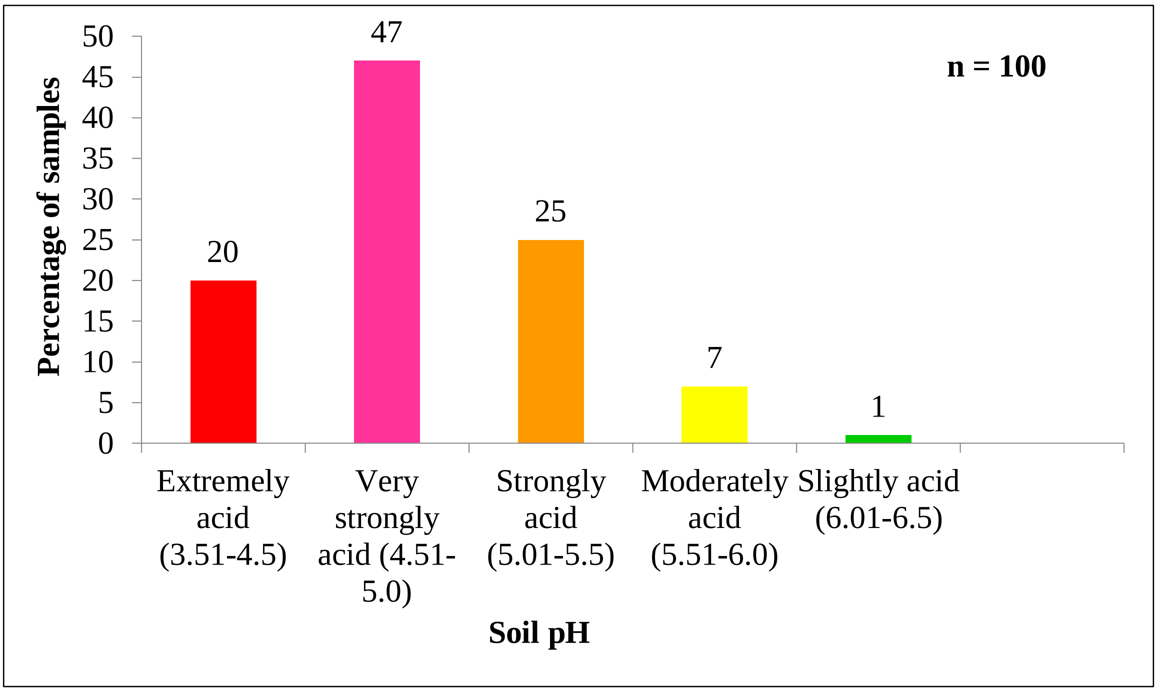

Fig. 11. Frequency distribution of soil pH in the post-flood soils of Mananthavady block in Wayanad district

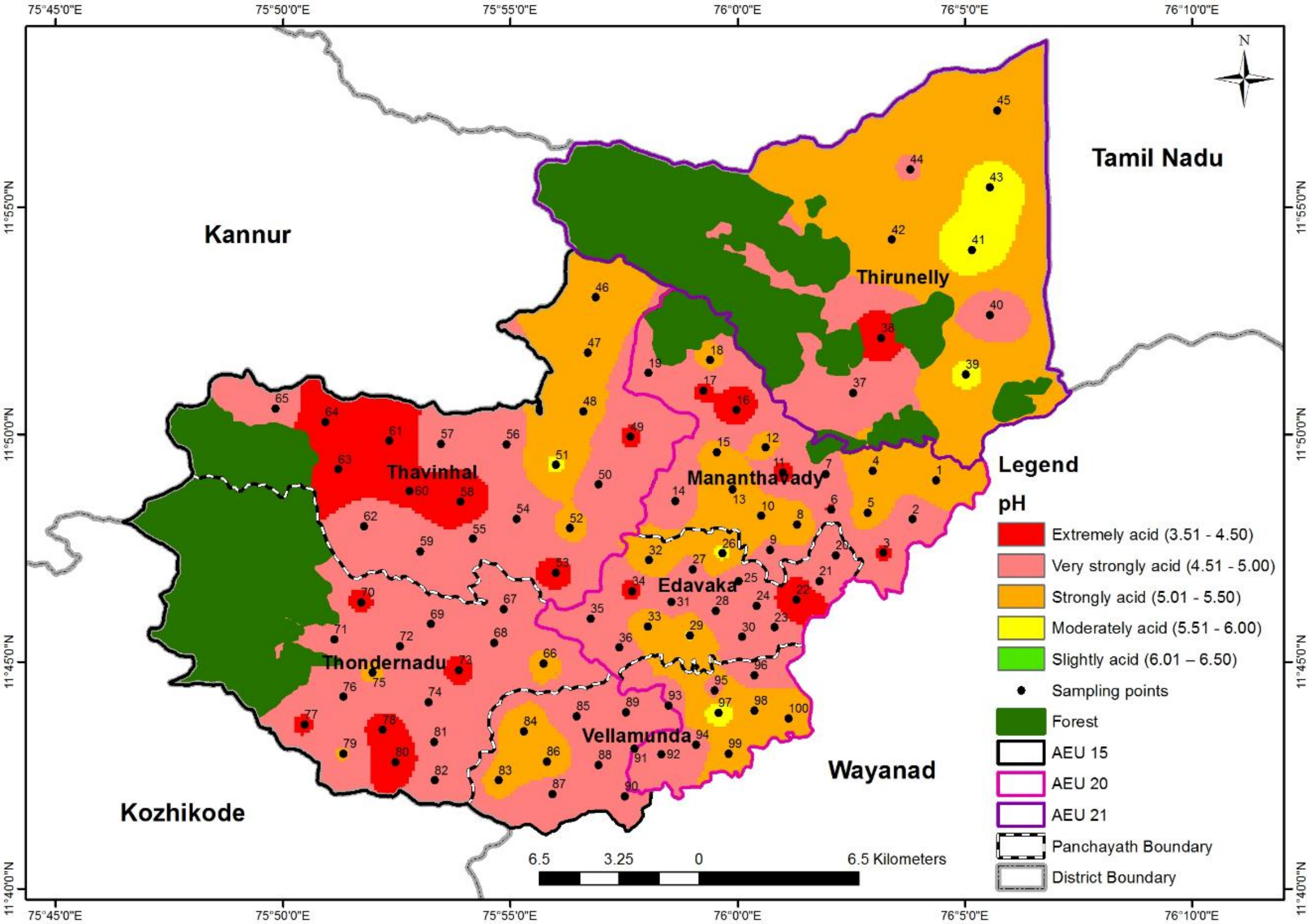

Fig. 12. Spatial variation of soil pH in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.2. Electrical conductivity

EC ranged between 0.04 dS m^{-1} and 0.76 dS m^{-1} in the area and it shows that EC was in the non saline range for all the samples. Flooding increased the dilution of soil, thereby decreasing electrical conductance indicating the absence of soluble ions at the soil surface (Ponnamperuma, 1984). Electrical conductivity is found to be increasing with increasing content of exchangeable sodium in the study area.

5.1.2.3. Exchangeable acidity

Exchangeable acidity varied between 0.55 to 6.96 cmol (p^+) Kg^{-1} in the study area. Exchangeable acidity showed a significant negative correlation with soil pH. This corroborates with the findings of Indira and Covilakom (2013). Majority of soils (51%) lies in the 2.0 to 4.0 cmol (p^+) Kg^{-1} range (Fig. 13).

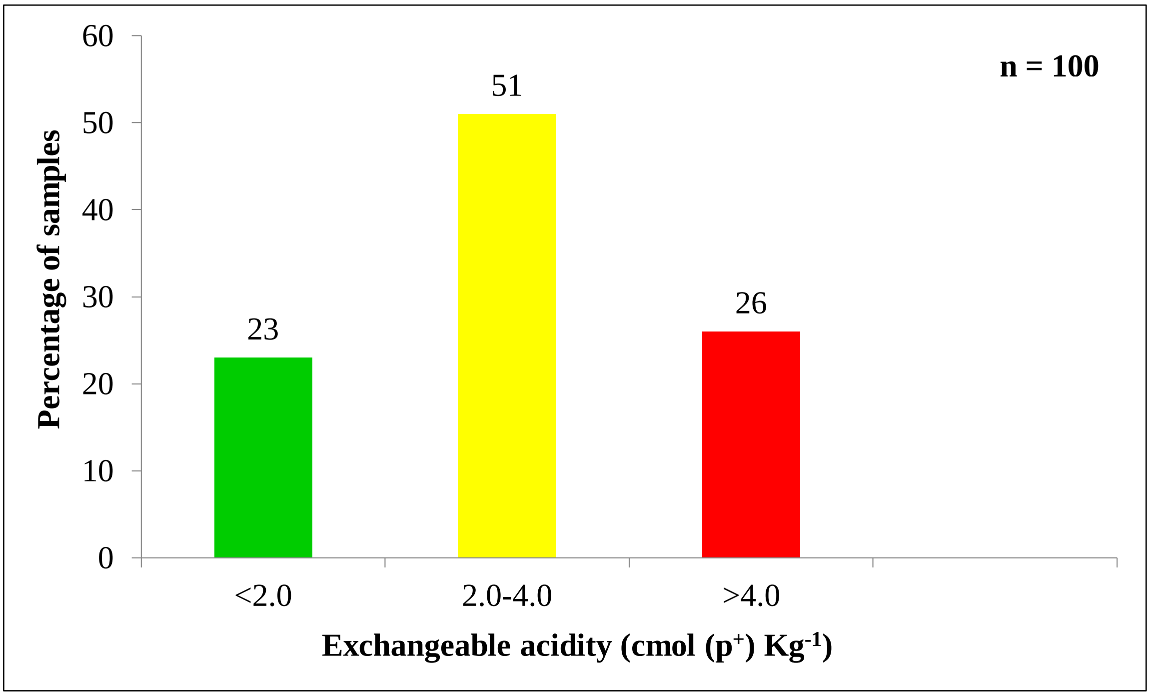

Fig. 13. Frequency distribution of exchangeable acidity in post-flood soils of Mananthavady block in Wayanad distric

5.1.2.4. Organic carbon

The organic carbon content of post flood soils of Mananthavady block ranged from 0.30 to 3.12%. Organic carbon content was high in 31% of the samples, medium in 61% of the samples and low in 8% of samples (Fig. 14). On the contrary, about 10%, 35% and 55% of soil samples in the block had low, medium and high organic carbon content in the pre-flood scenario (KSPB, 2013). The spatial distribution of organic carbon content in the post flood soils of Mananthavady block is depicted in Fig. 15. The higher organic carbon content was observed in the areas where sedimentation occurred. A decrease in per cent samples with high organic carbon compared to the pre-flood data might be due to the washing away of organic matter by the heavy flowing flood water. Similar result was reported by Akpoveta *et al*. (2014) who observed a decline in organic carbon content on flooding due to leaching of organic carbon such as organic acids and humus.

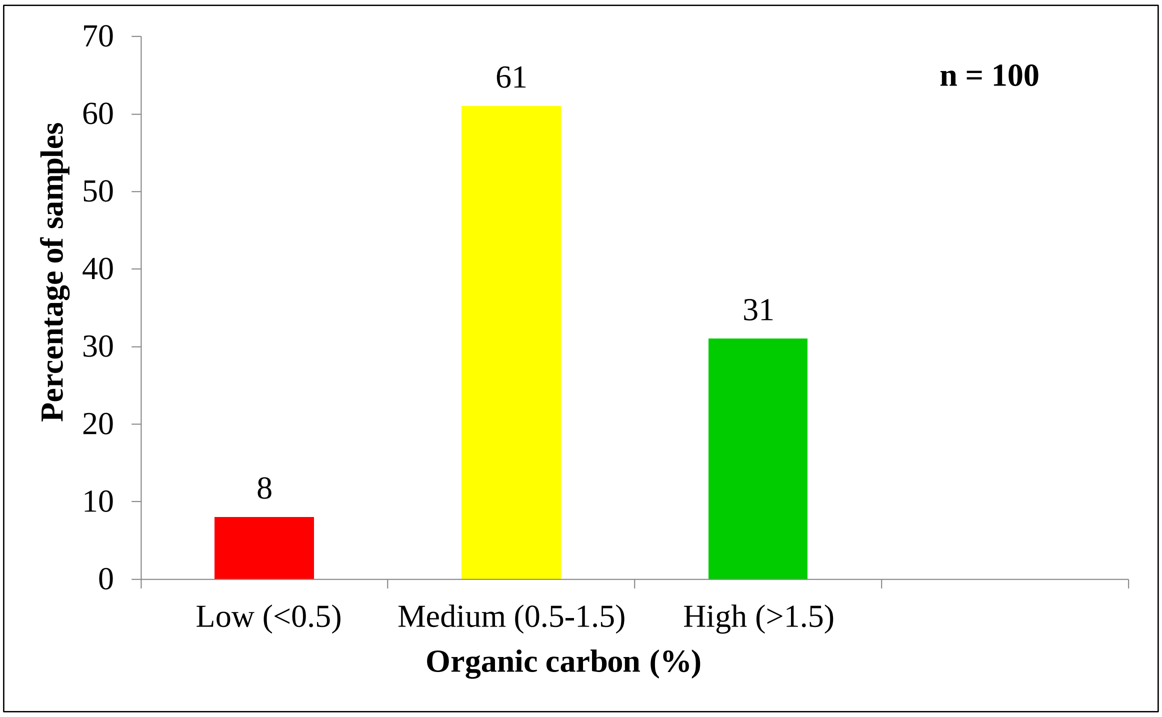

Fig. 14. Frequency distribution of organic carbon in the post-flood soils of Mananthavady block in Wayanad district

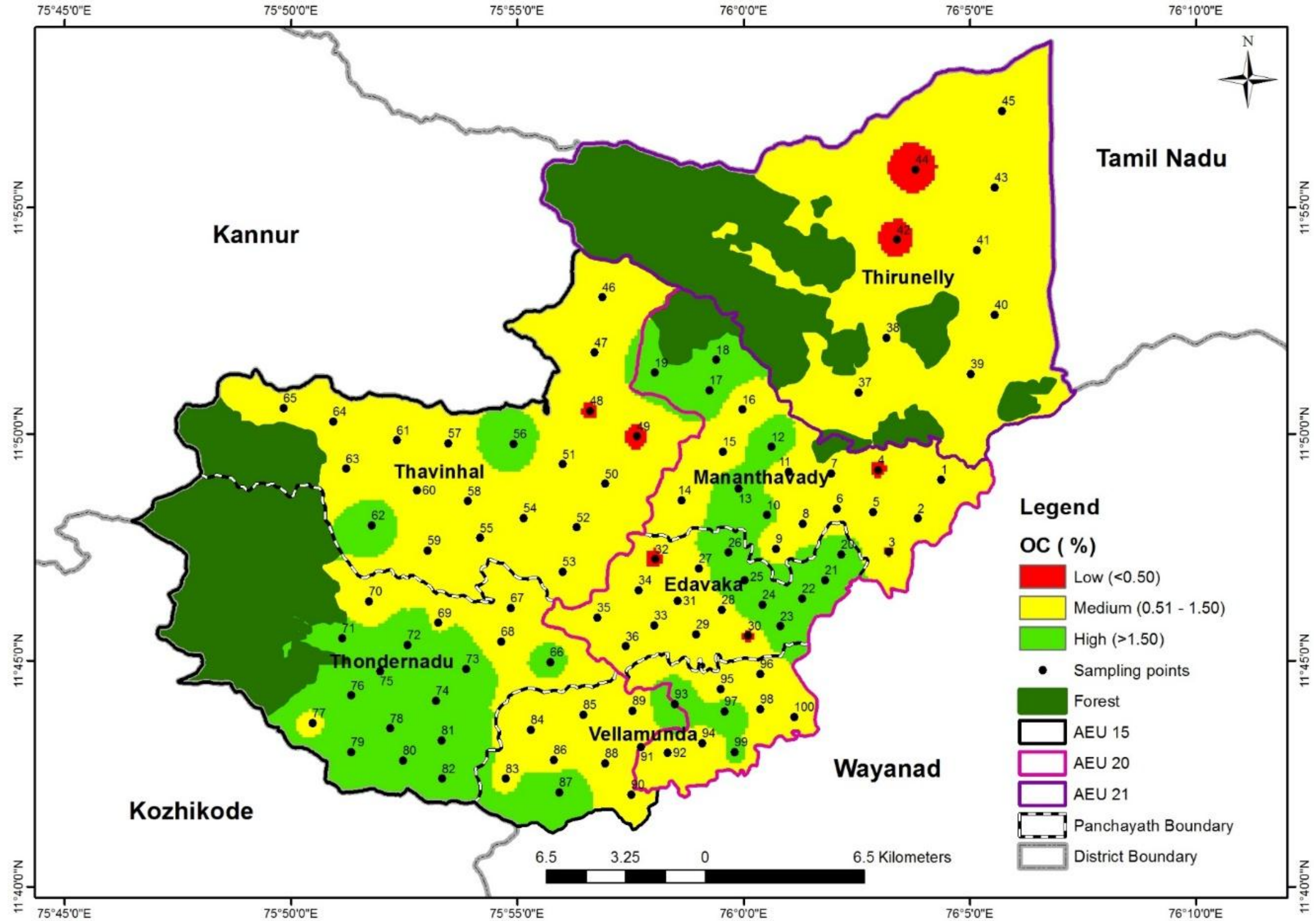

Fig. 15. Spatial variation of organic carbon in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.5. Available nitrogen

Available N varied between 112.90 and 332.42 kg ha^{-1}. A significant positive correlation reported between available nitrogen content and organic carbon in the present study (r= 0.435**). Very low available N contents were reported from crop lands with low organic carbon content (Thirunelly) and it was found to be significantly negatively correlated with sand content. About 94% of soil samples showed a low range and 6% showed a medium range of available nitrogen (Fig. 16). The low availability of nitrogen in soil might be due to leaching of nitrate nitrogen present in soil and also due to nitrogen loss through nitrate reduction and denitrification under anaerobic condition (Unger *et al.*, 2009a). Also the low mineralization and decomposition of organic matter under highly acidic soils might also contributed to the low nitrogen content even with medium to high organic carbon status of the soils under the study. The spatial distribution of available nitrogen in the post flood soils of Mananthavady block depicted in Fig. 17.

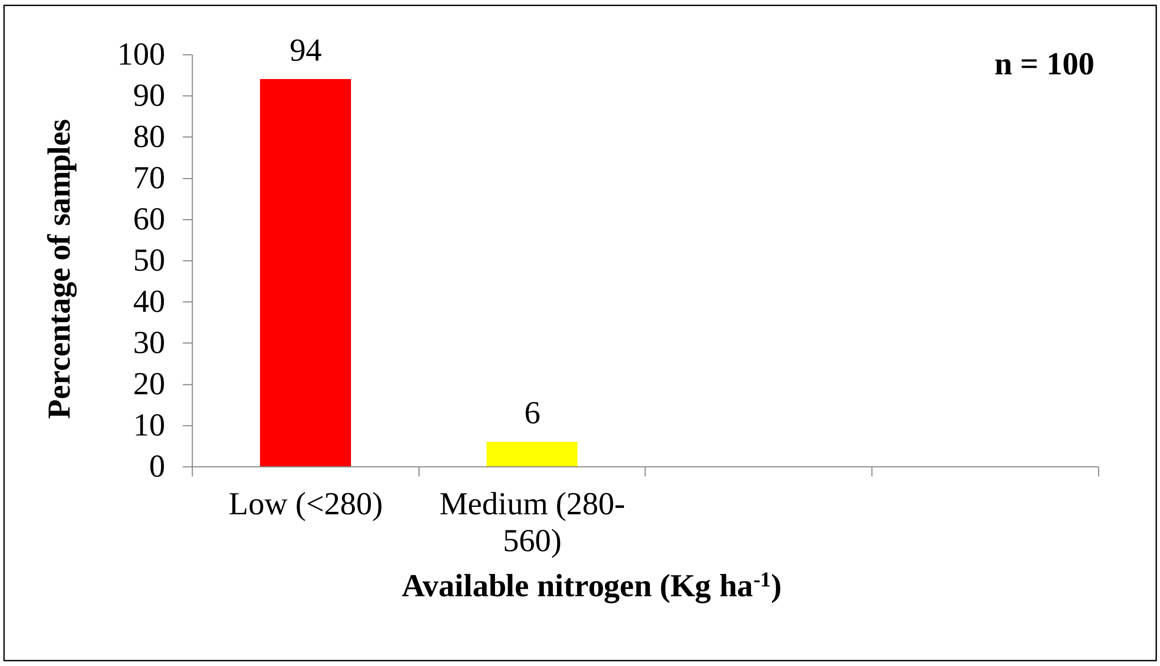

Fig. 16. Frequency distribution of available nitrogen in the post-flood soils of Mananthavady block in Wayanad district

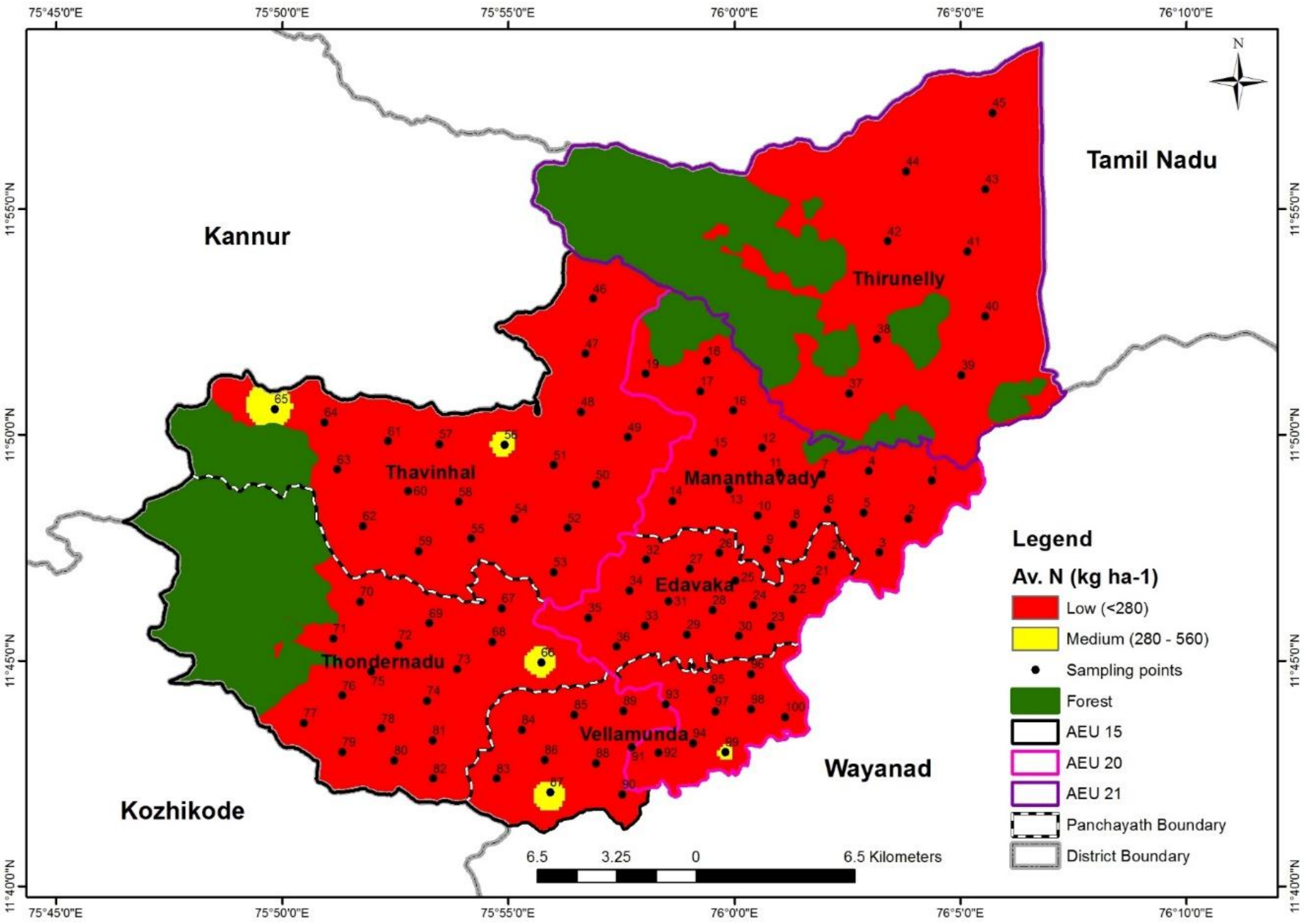

Fig. 17. Spatial variation of available nitrogen in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.6. Available phosphorus

Available P varied from 15.43 to 183.75 kg ha^{-1} and was found to be medium status in 56% of the soils, and high in 44% of the soils (Fig. 18). About 49% of soils were high, 20% of soils were medium and 31 % of soils were low in available phosphorus in the pre flood scenario (KSPB, 2013). The present study showed that phosphorus and iron contents were high in the study area. Up-on inundation release of large quantity of phosphorous takes place as a result of reduction of iron (Loeb *et al.*, 2008). Also most of the farmers in the area are regularly applying phosphatic fertilizers like factomphos, rajphos, and diammonium phosphate in the field. These might be the reason for an increase in per cent of available P in medium range as compared to pre flood.

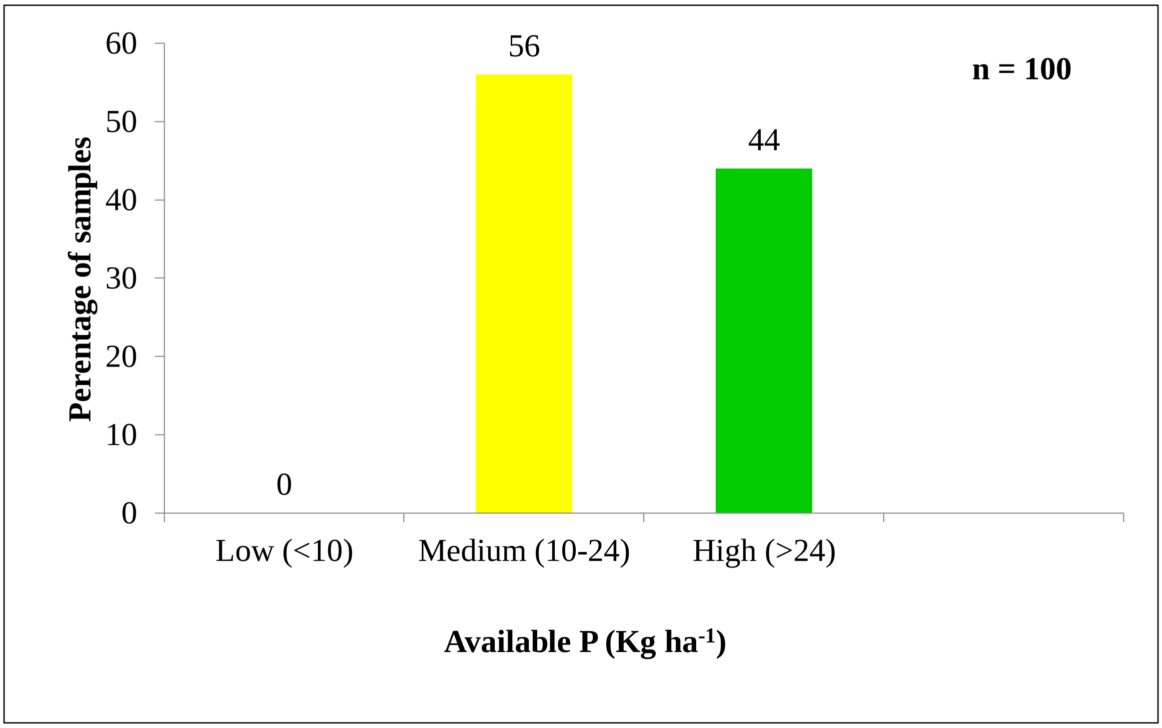

Fig. 18. Frequency distribution of available phosphorus in the post-flood soils of Mananthavady block in Wayanad district

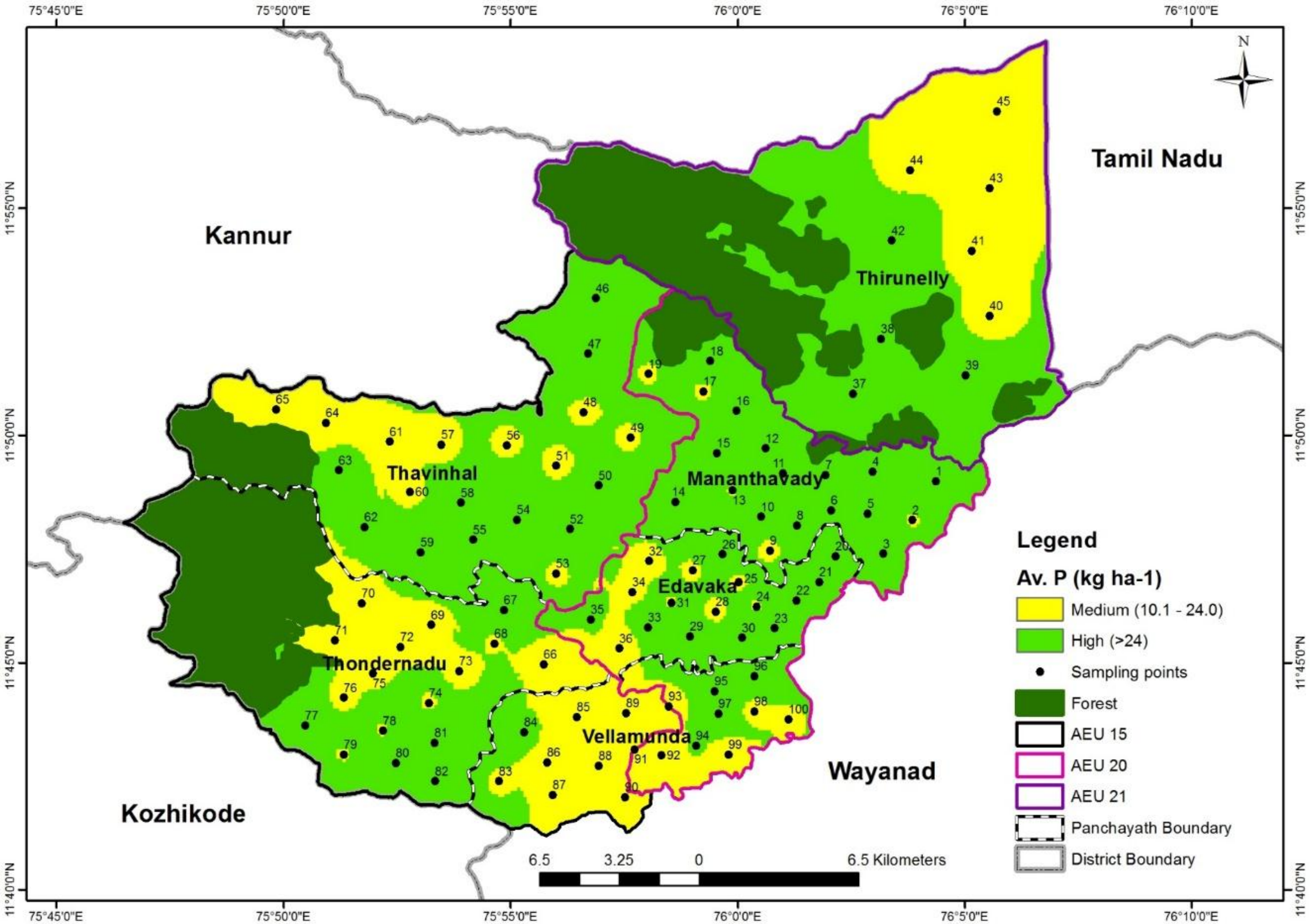

Fig. 19. Spatial variation of available phosphorus in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.7. Available potassium

The available potassium of post flood soils of block ranged from 36.18 kg ha^{-1} to 737.30 kg ha^{-1}. Majority (41%) of the soils was medium in available K, 22% high and 37% low (Fig. 20). On the contrary, about 25%, 59% and 16% per cent of soil samples in the Mananthavady bock had low, medium and high available potassium in the pre flood scenario (KSPB, 2013). Available K had a significant positive correlation with ECEC and electrical conductivity. Similar correlations were reported by Behara and Shukla (2014) in loamy sand to sandy loam textured soils of India. Spatial variability of available K is presented in Fig. 21. A decline in concentration of potassium content was observed in the flood affected areas of the Mananthavady block. It was similar to the findings of Akpoveta *et al*. (2014) where reduced level of potassium was observed on flooding of farmlands of Asaba and Onitsha in Nigeria. Potassium might have got leached out during flood.

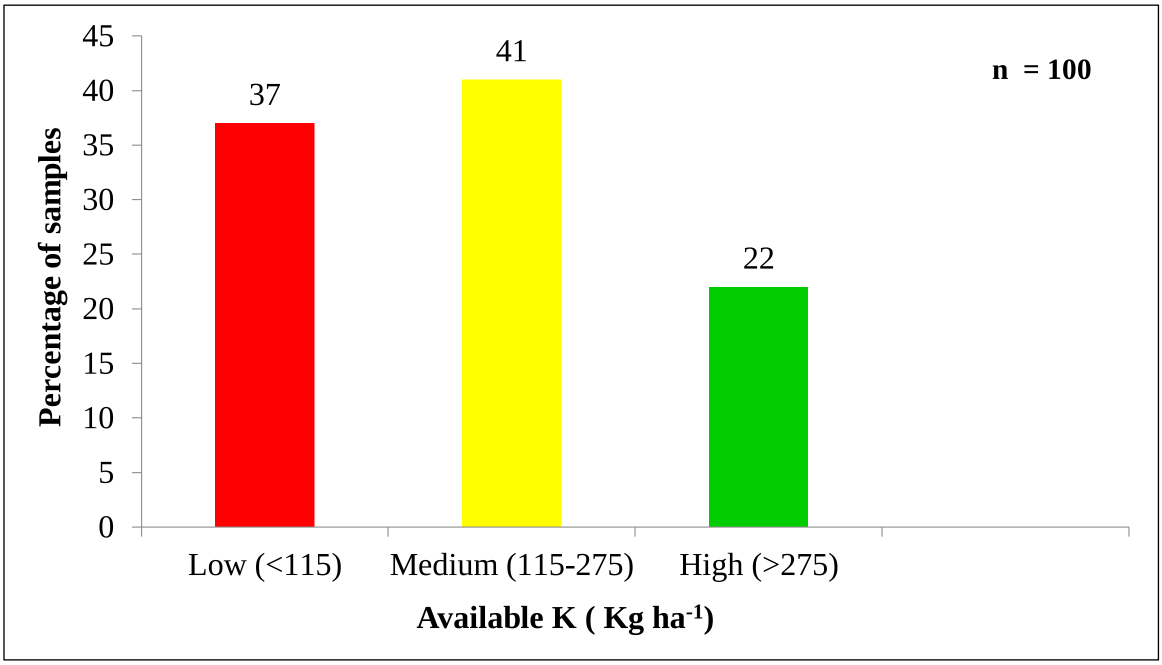

Fig. 20. Frequency distribution of available potassium in the post-flood soils of Mananthavady block in Wayanad district

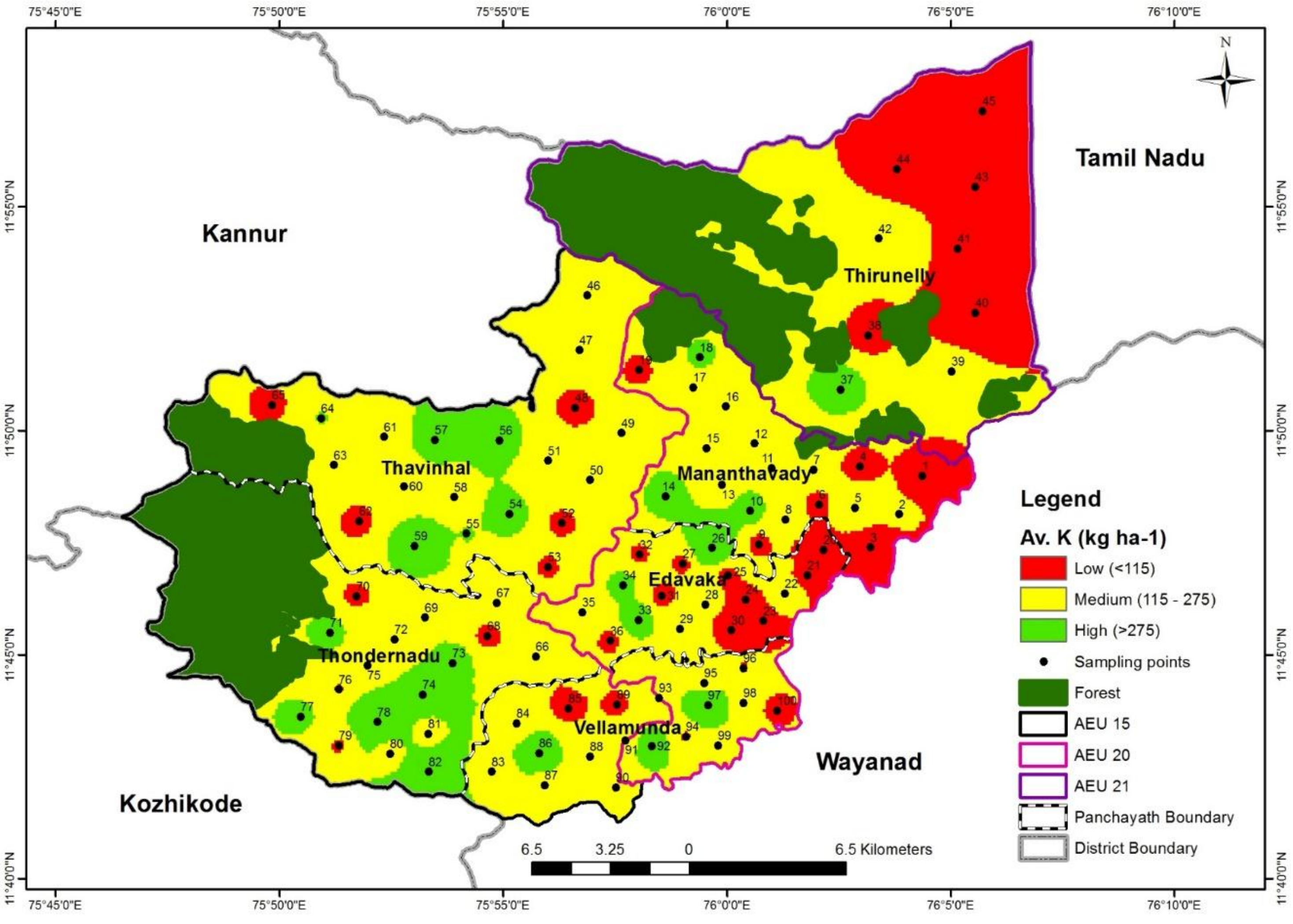

Fig. 21. Spatial variation of available potassium in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.8. Available calcium

Available Ca ranged between 220 mg kg^{-1}(Thavinhal) and 2860 mg kg^{-1}(Thirunelly) in the study area. Available calcium content in soil increased after the occurrence of flood. That is available calcium was adequate in 87% and deficient in 13% of samples (Fig. 22) in contradiction with pre flood condition where only 36% of soil samples were sufficient in available calcium content. Similar observation was reported by Kalshetty *et al*. (2012) while conducting a study on the effect of river Krishna flood on soil properties of cultivated areas in Bagalkot district, Karnataka state. Application of liming materials like lime and dolomite has led to an increase in calcium content of soil. Available Ca was found to have a significant positive correlation with soil pH and clay content. Spatial variability of available Ca is presented in Fig. 23.

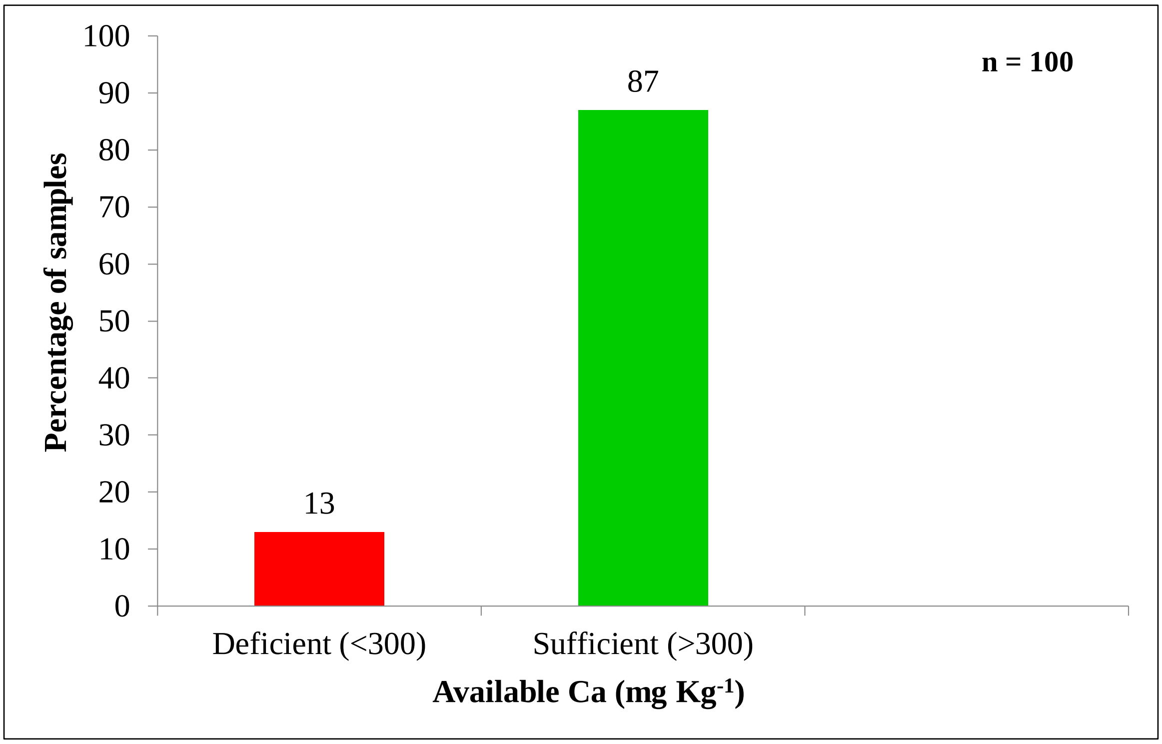

Fig. 22. Frequency distribution of available calcium in the post-flood soils of Mananthavady block in Wayanad district

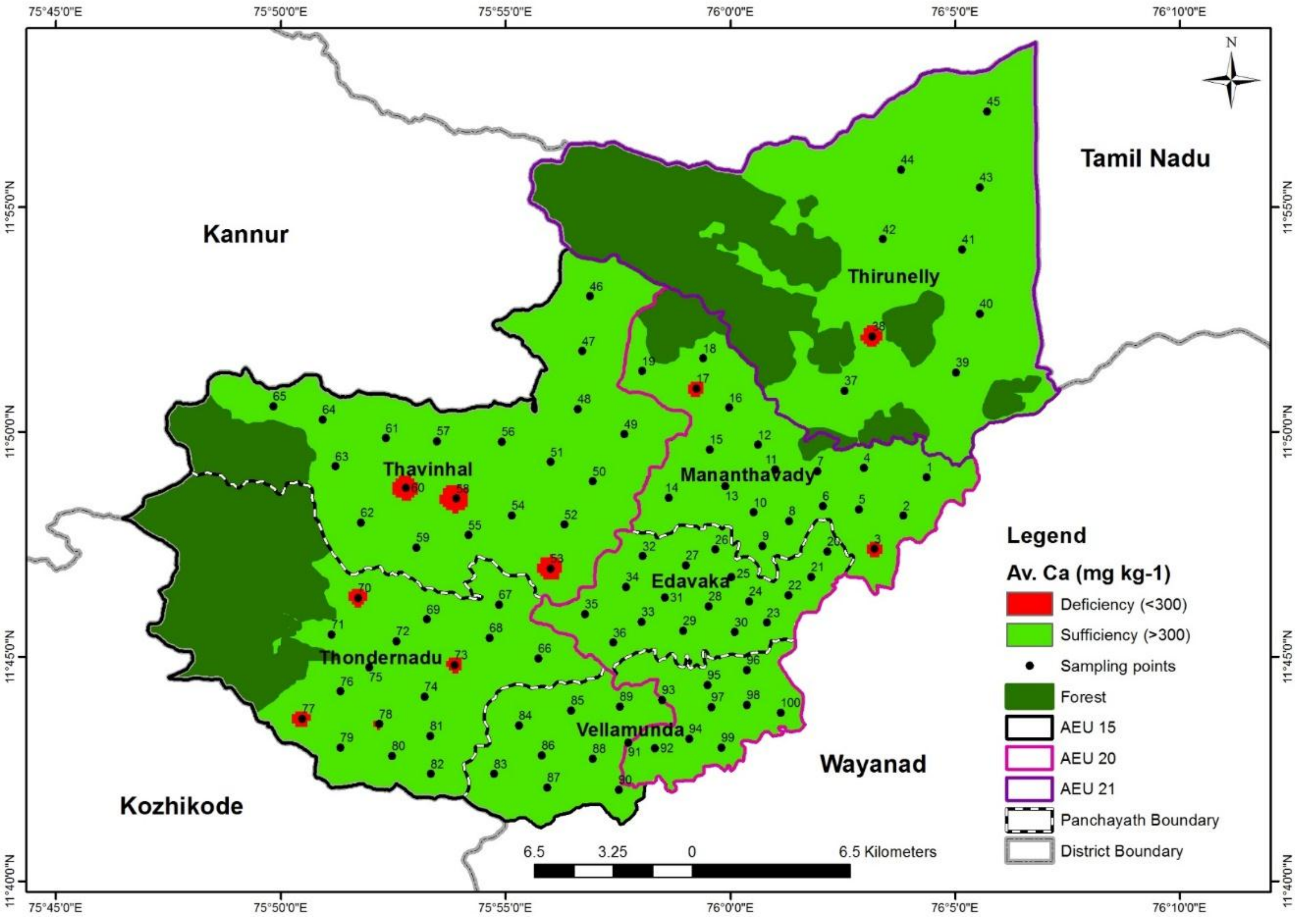

Fig. 23. Spatial variation of available calcium in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.9. Available magnesium

Available magnesium was found to be sufficient in 93% of soil samples and deficient in 7% of the post flood soils of Mananathavady block (Fig.24) whereas it was sufficient in only (38%) in pre-flood soils. Available Mg varied between 84 mgkg^{-1}(Thavinhal) and 1224 mgkg^{-1} (Thirunelly). Most of the farmers were using dolomite for liming as it is a low cost liming material as well as dual nutrient supply of dolomite (Ca and Mg). This might be the reason for increased magnesium content of soils as compared to pre flood scenario. Available Mg had a significant positive correlation with soil pH, available Ca, ECEC and clay content and it showed a negative correlation with sand content. Higher Mg levels were observed in soils with high Ca and strongly acid to moderately acidic pH. The spatial variability in available Mg is presented in Fig. 25.

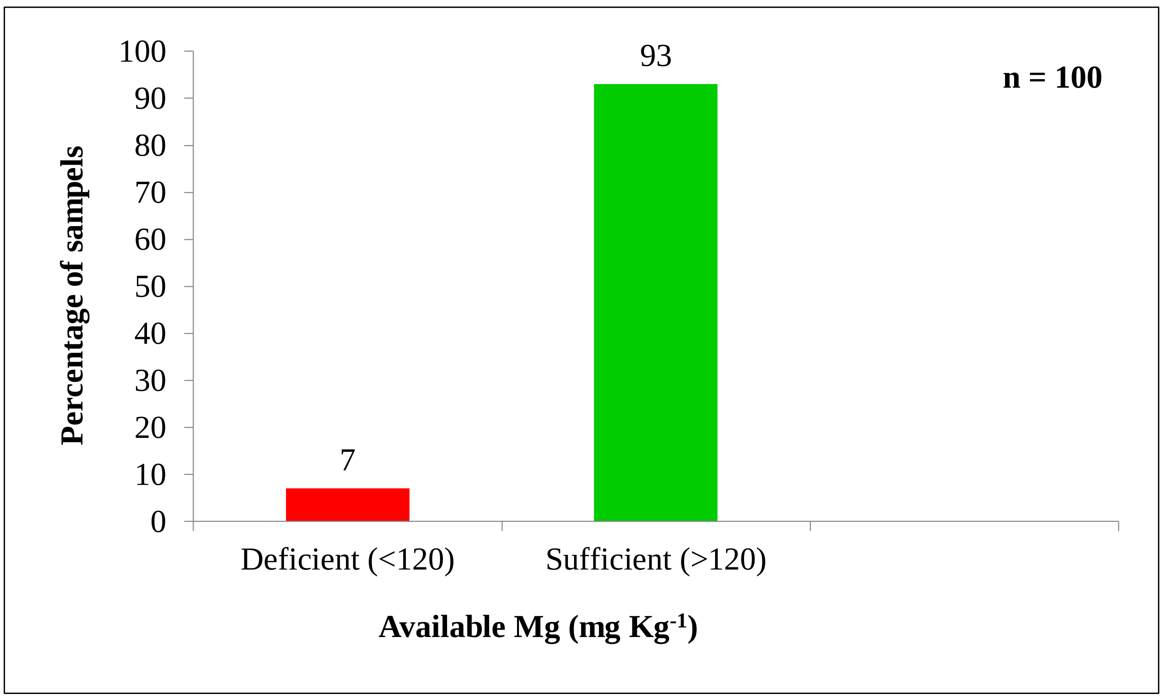

Fig. 24. Frequency distribution of available magnesium in the post-flood soils of Mananthavady block in Wayanad district

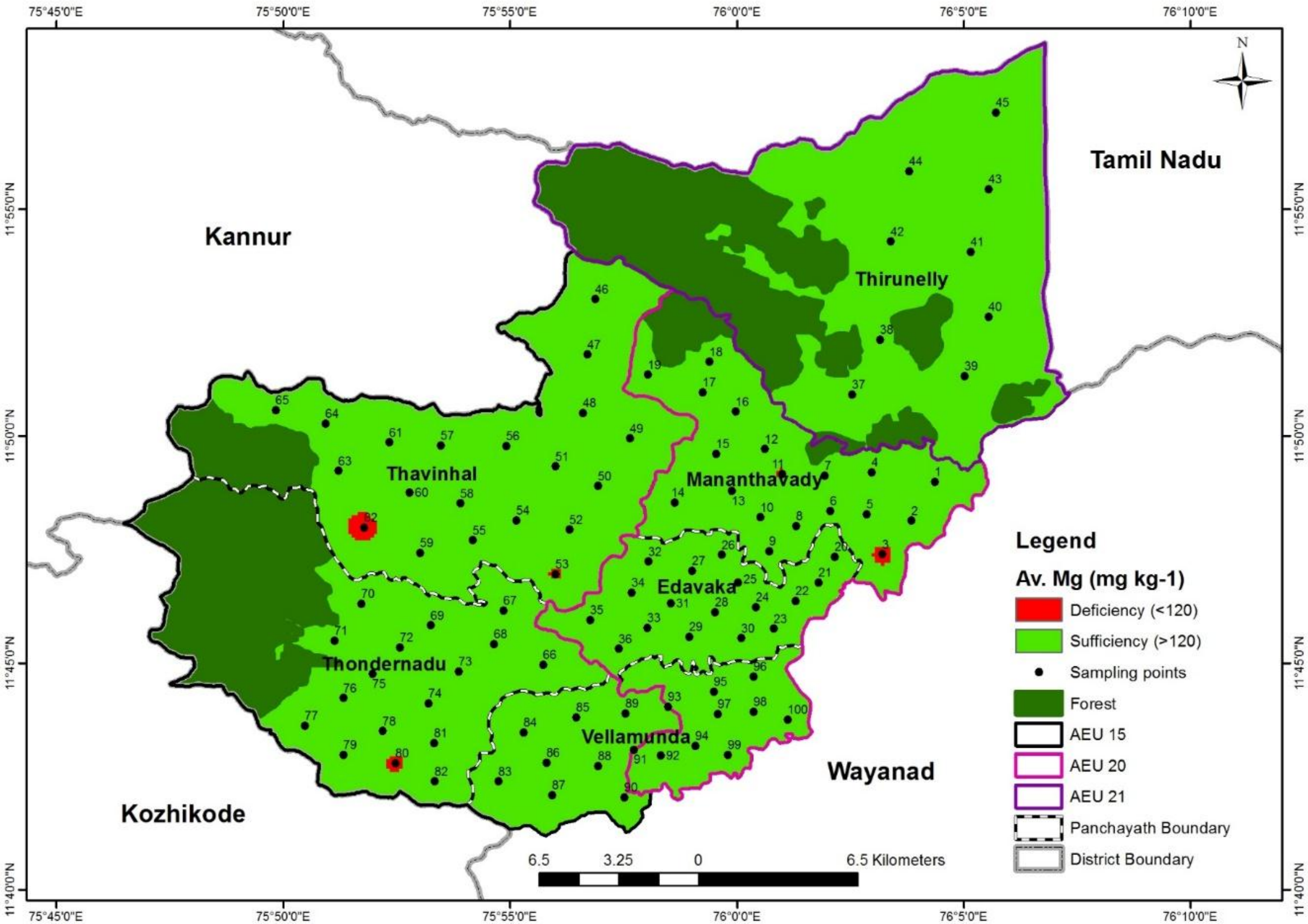

Fig. 25. Spatial variation of available magnesium in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.10. Available sulphur

Available S varied between 0.45 mg kg^{-1} and 8.73 mg kg^{-1}. Available S was deficient for 85% of samples (Fig. 26). Post flood samples showed a substantial decrease in available S content when compared with the pre flood values where only 64 % of the soil samples were deficient (KSPB, 2013). Soluble sulphates undergo rapid leaching losses thereby reducing available S content in soils. Comparatively very low available sulphur was reported from hilly regions like Thavinhal (1.90 mg kg^{-1}) and Thirunelly (1.95 mg kg^{-1}). Spatial variability of available S is presented in Fig. 27.

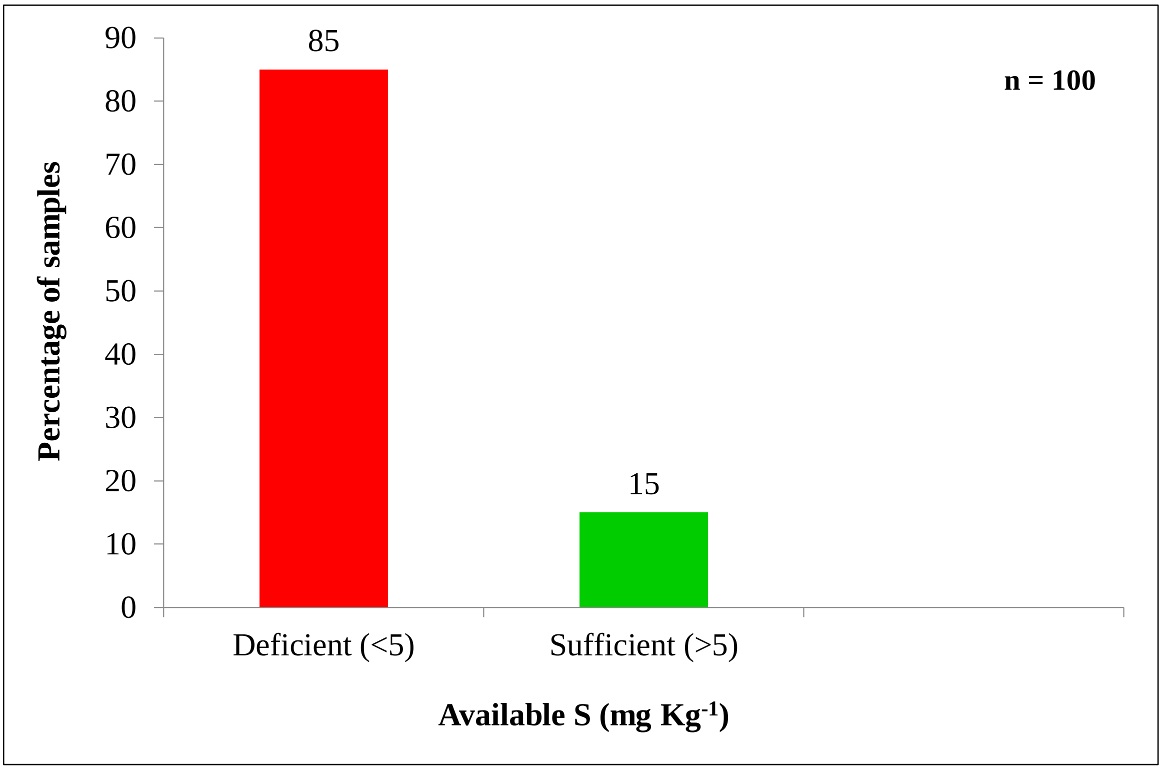

Fig. 26. Frequency distribution of available sulphur in the post-flood soils of Mananthavady block in Wayanad district

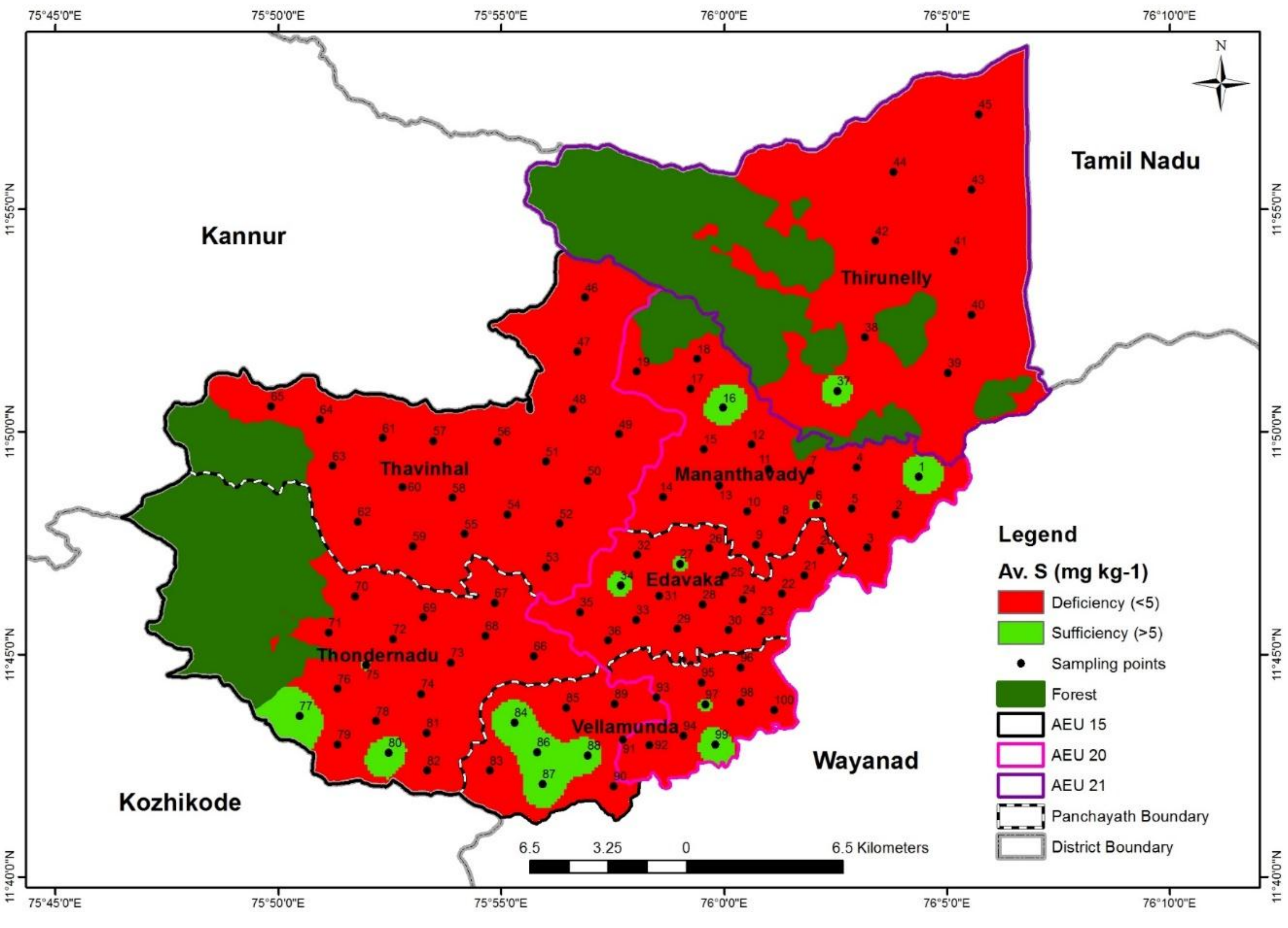

Fig. 27. Spatial variation of available sulphur in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.11. Available iron

Available iron was found to be adequate (100%) in all the post flood soils of Mananathavady bock. Spatial variability of available Fe is presented in Fig. 28. The available Fe varied between 16.48 mg kg^{-1} (Thavinhal) and 344.80 mg kg^{-1} (Mananthavady).The high content of available iron in the post flood soil might be due to the reduction of insoluble form to more soluble form (Fe^{2+}) under submerged condition (Vepraskas and Faulkner, 2001).

5.1.2.12. Available manganese

The available Mn varied between 6.42 mg kg^{-1} (Thavinhal) and 189.70 mg kg^{-1} (Mananthavady).Available manganese content was adequate in 100 % of samples (Fig. 29). Rajashekaran *et al*. (2014) reported that there were no deficiencies of available Fe and Mn in Kerala soils. Spatial variability of available Mn is presented in Fig. 29.

5.1.2.13. Available zinc

Available zinc was found to be sufficient (100%) in all the post flood soils of Mananathavady block (Fig. 30). The available Zn varied between 1.96 mg kg^{-1}(Thondernadu) and 28.50 mg kg^{-1} (Vellamunda). There was an increase of 47% in sufficient range of available Zn in post flood scenario as compared to pre food (KSPB, 2013). Spatial variability of available Zn is depicted in Fig. 30.

5.1.2.14. Available copper

Available copper content was adequate in 73 % and deficient in 27 % of samples (Fig.31). Post flood samples showed a substantial increase of 8% in sufficient level of available copper when compared with the pre flood values (KSPB, 2013).The available copper ranged between 0.10 mg kg^{-1} and 11.74 mg kg^{-1}. Spatial variability of available Cu is depicted in Fig. 31. The high moisture content in the soil resulting from flood could have created conducive condition in the soil for the metals to be present in highly available form (Akpoveta *et al*., 2014).

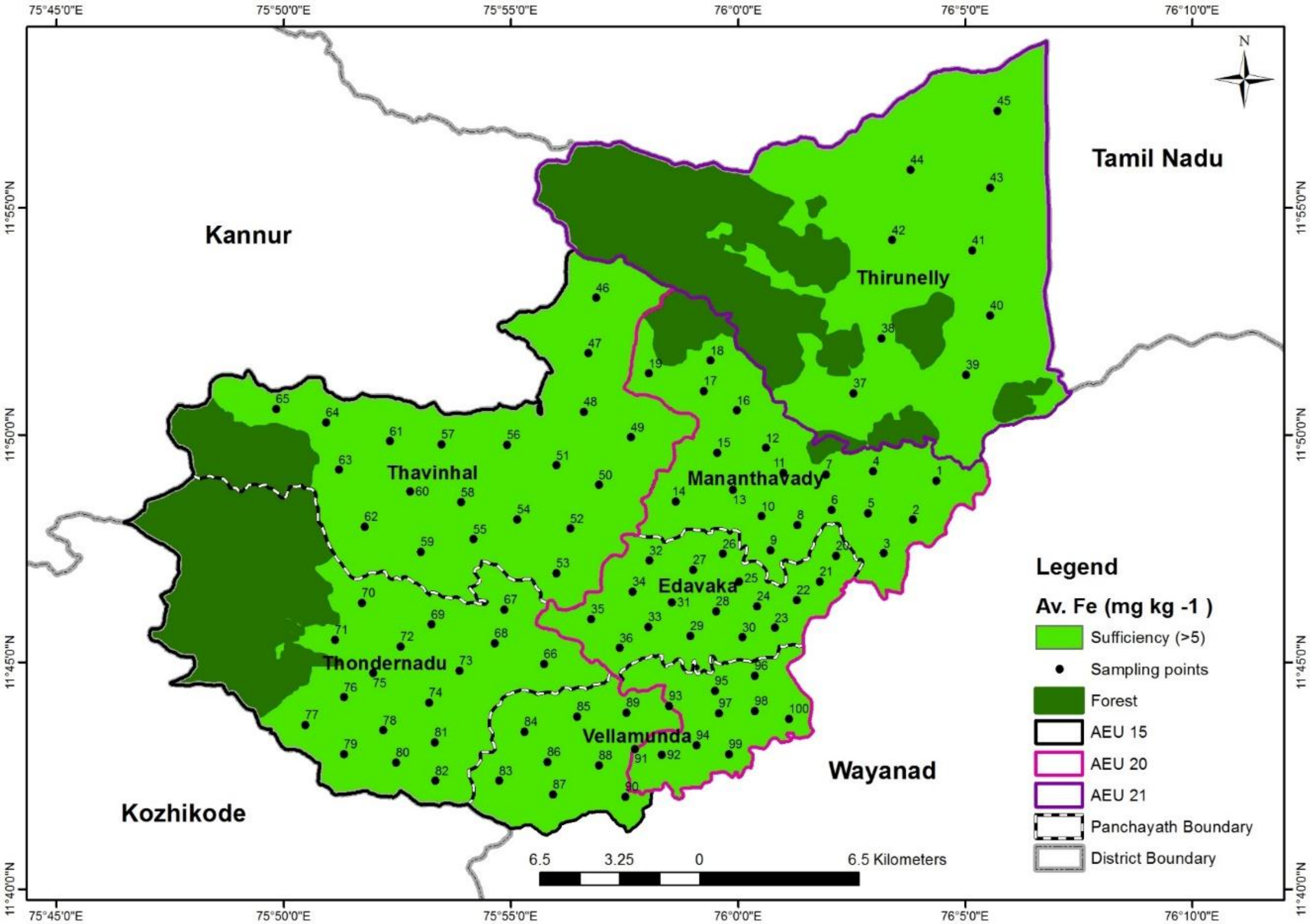

Fig. 28. Spatial variation of available iron in the post-flood soils of Mananthavady block in Wayanad district

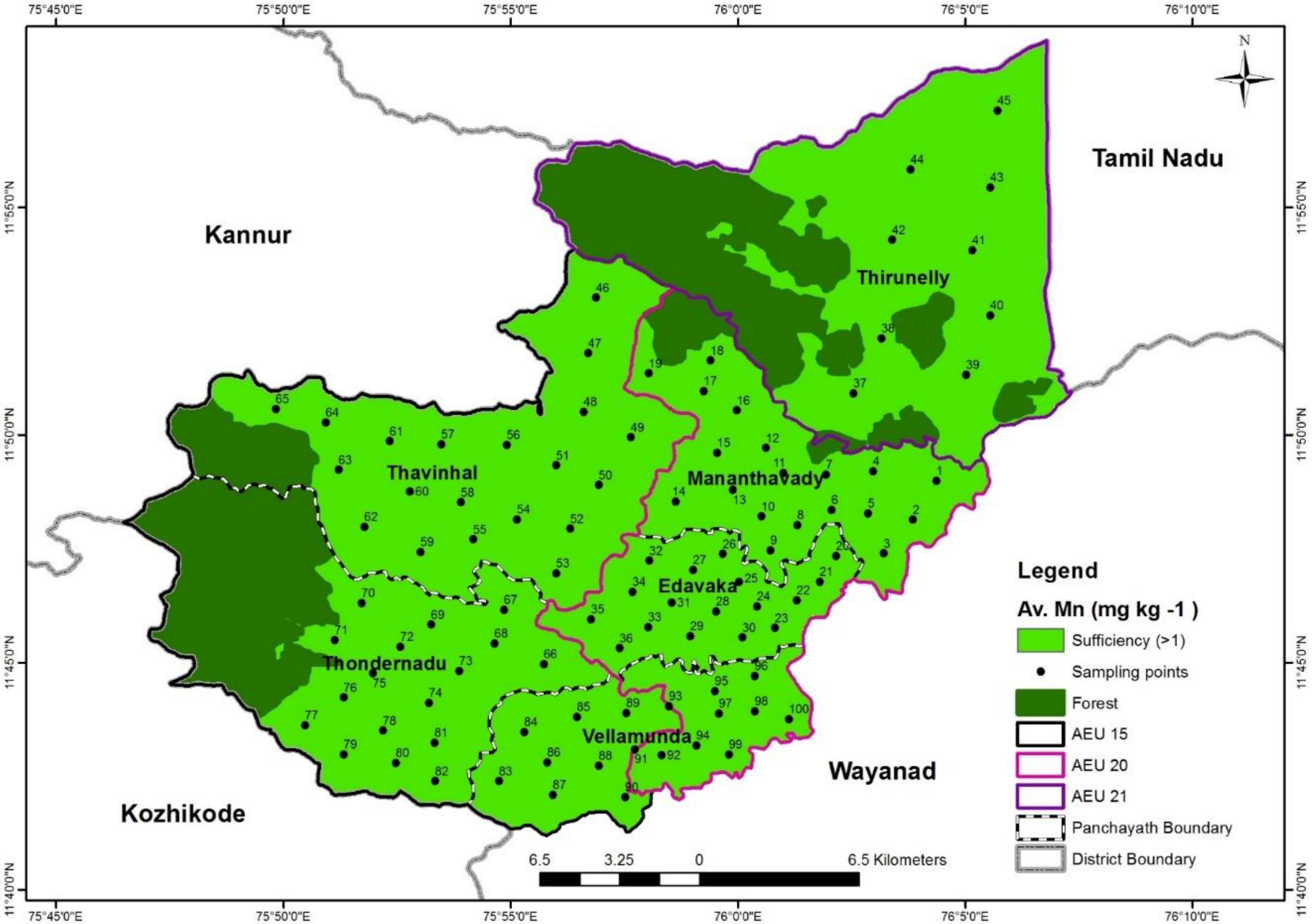

Fig. 29. Spatial variation of available manganese in the post-flood soils of Mananthavady block in Wayanad district

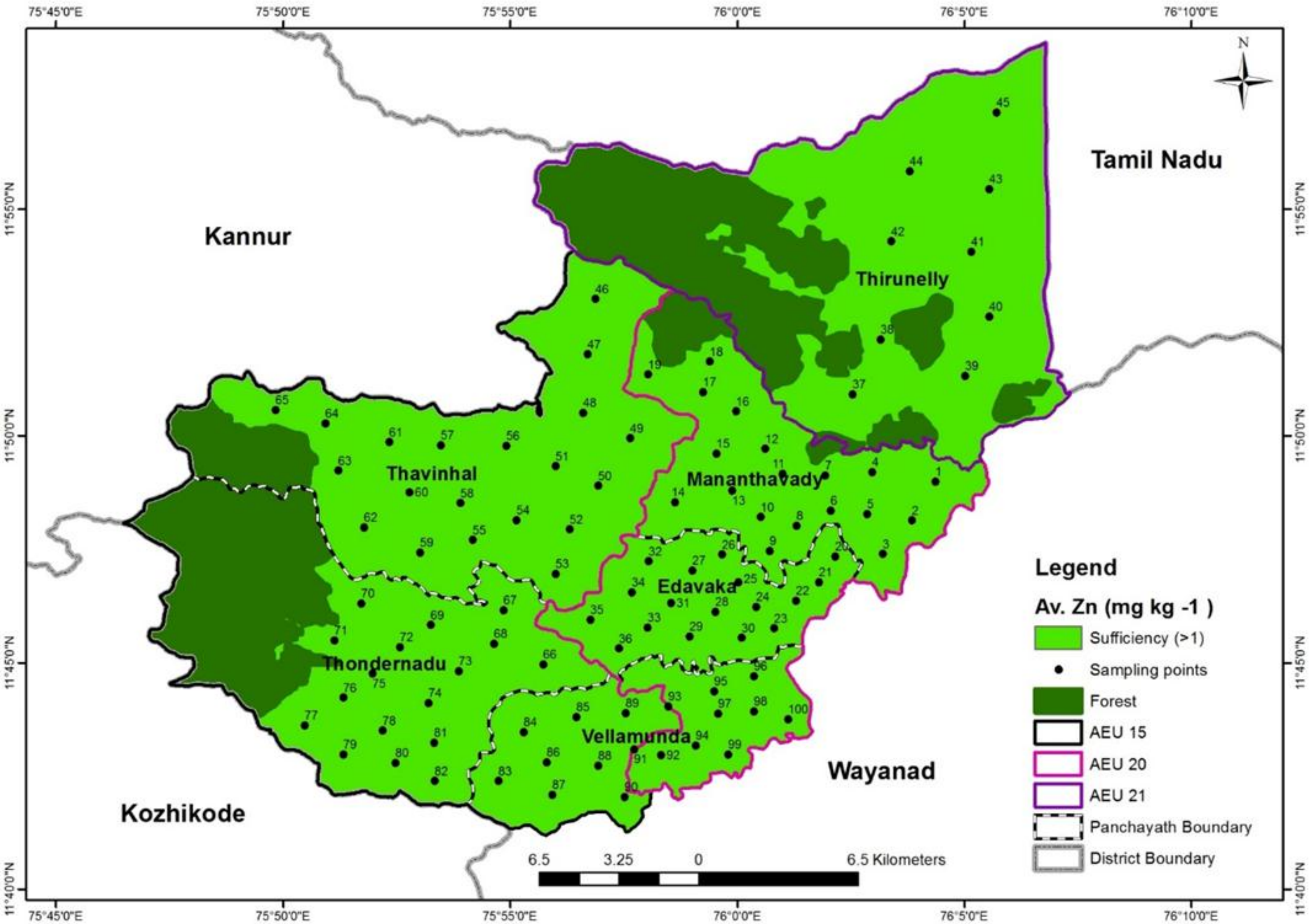

Fig. 30. Spatial variation of available zinc in the post-flood soils of Mananthavady block in Wayanad district

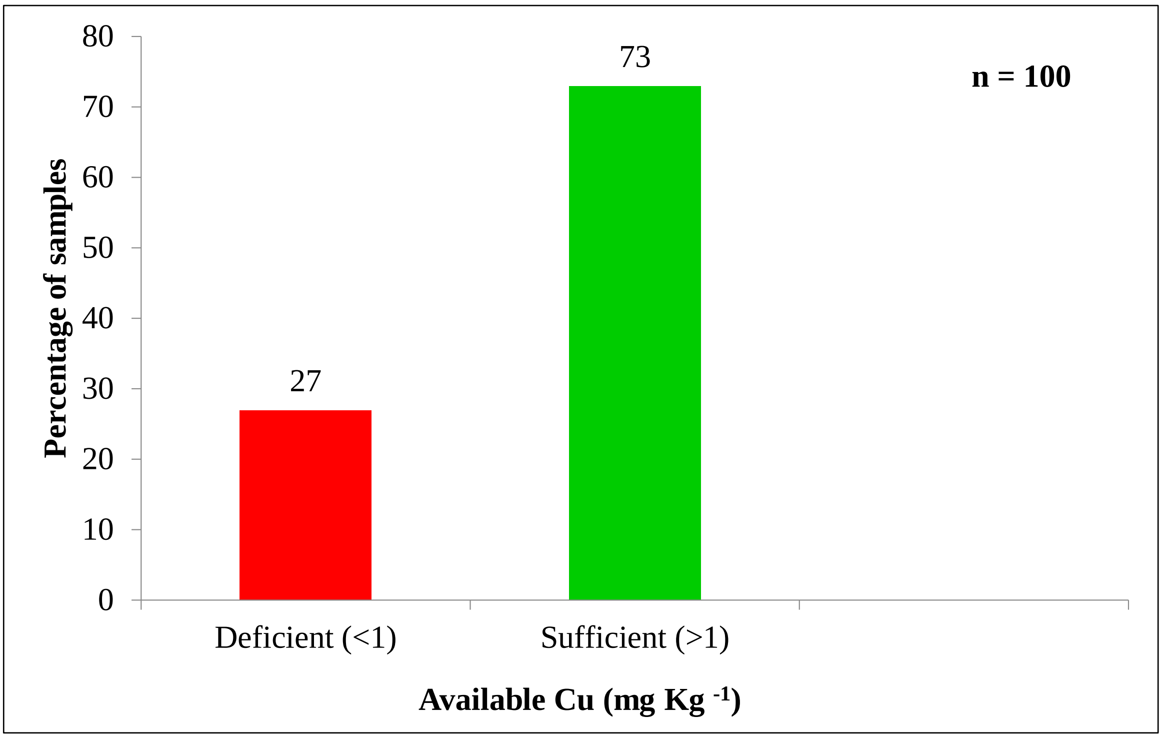

Fig. 31. Frequency distribution of available copper in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.15. Available boron

Available boron varied between 0.05 and 0.12 mg kg^{-1} and it was found to be deficient (100%) in all the post flood soils of Mananathavady bock (Fig.33). On the contrary, about 93% of soil samples were deficient and 7% adequate in available boron in the pre flood scenario (KSPB, 2013). The acid leaching environment of soils of Kerala is not favorable for the retention of boron in the soil and there is acute deficiency of available B in Kerala soils (Rajashekaran *et al*., 2014).

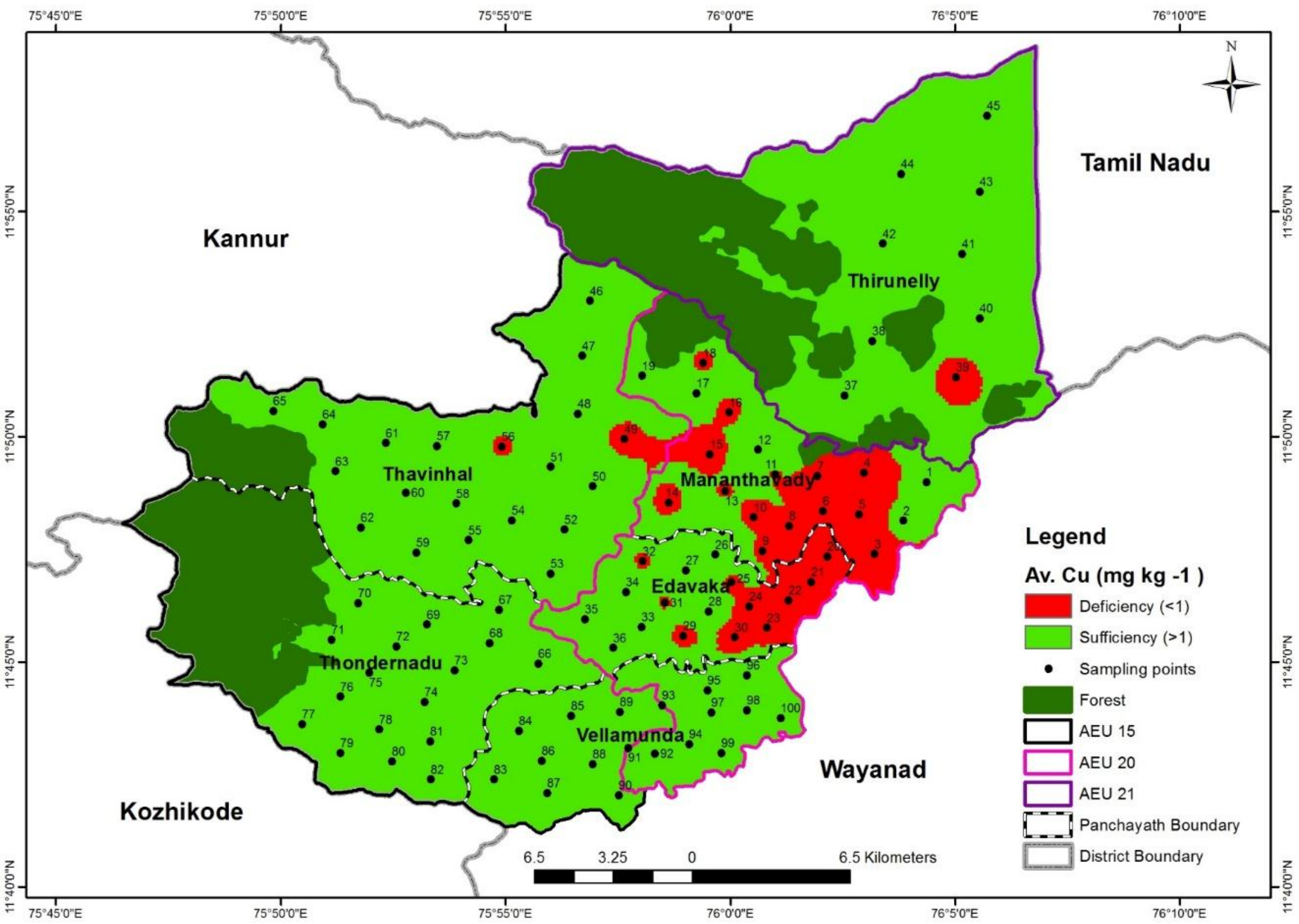

Fig. 32. Spatial variation of available copper in the post-flood soils of Mananthavady block in Wayanad district

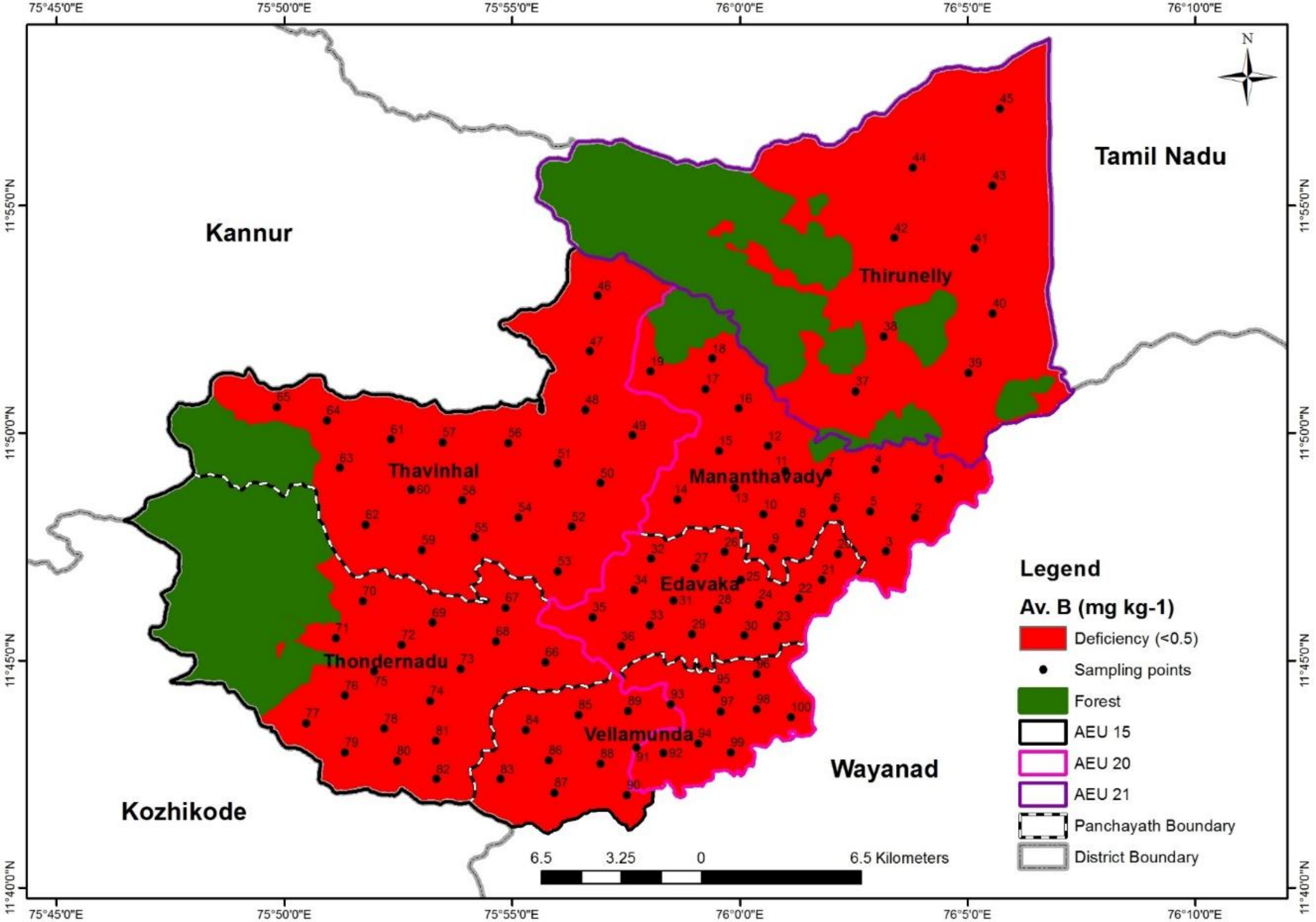

Fig. 33. Spatial variation of available boron in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.16. Exchangeable Na

Exchangeable sodium varied between 0.12 cmol (p^+) Kg^{-1} and 0.43 cmol (p^+) Kg^{-1}. Exchangeable sodium was low for 96% of samples (Fig. 34). Exchangeable Na had a significant positive correlation with EC, clay content, organic carbon and available N, Ca, and Mg.

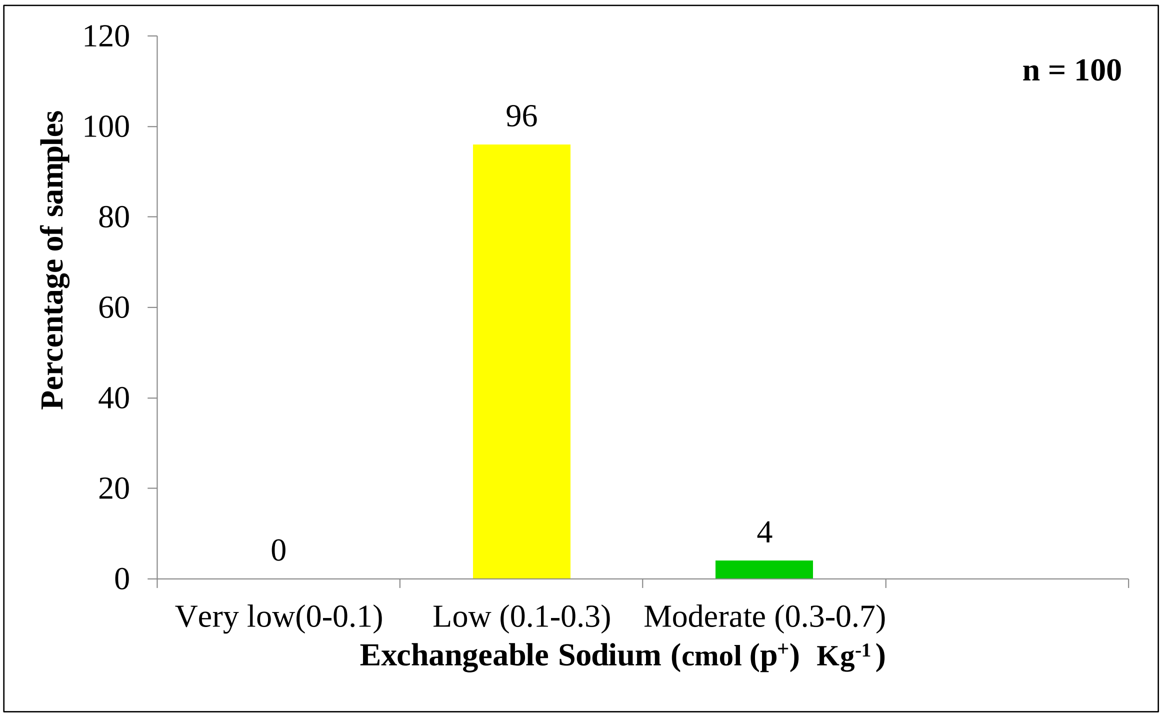

Fig. 34. Frequency distribution of exchangeable sodium in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.17. Exchangeable Al

Exchangeable Al varied between 0.50 and 6.72 cmol (p^+) Kg^{-1} in the study area (Fig 35). Exchangeable Al showed a significant negative correlation with soil pH and significant positive correlation with exchangeable acidity. Similar result was reported by Abreu Jr *et al.* (2003) and Indira and Covilakom (2013). Most of the area had exchangeable Al between 2 and 4 cmol (p^+) Kg^{-1}(49%). The major portion of exchangeable acidity was contributed by exchangeable Al only (Table 12).

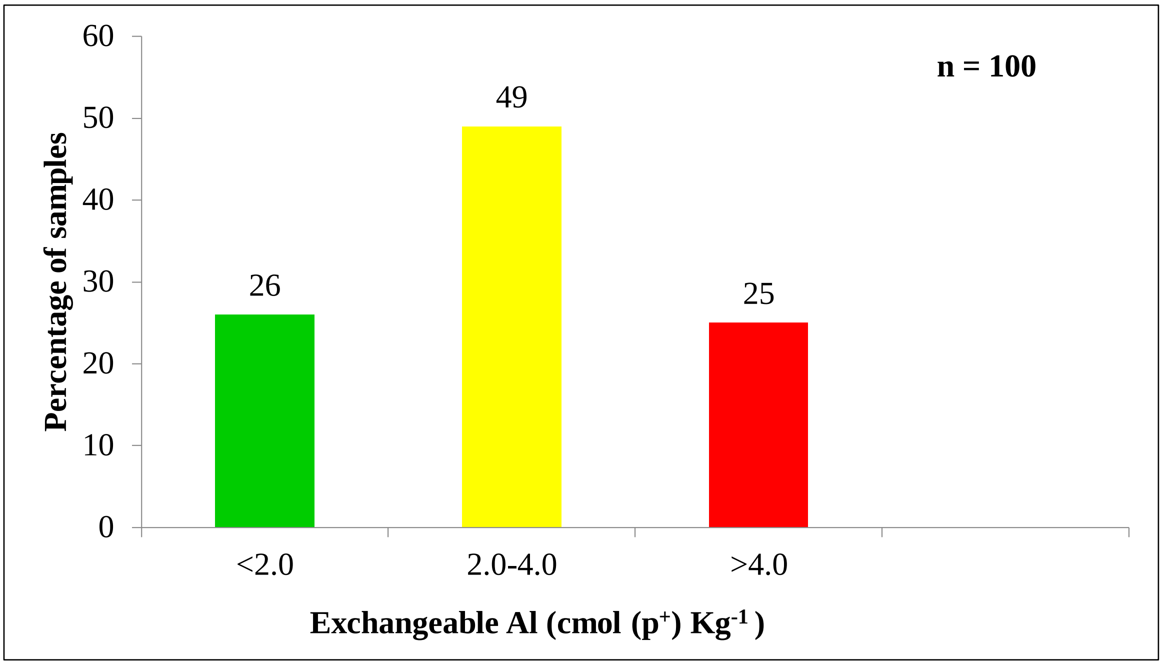

Fig. 35. Frequency distribution of exchangeable aluminium in the post-flood soils of Mananthavady block in Wayanad district

5.1.2.18. Effective cation exchange capacity

Effective cation exchange capacity ranged between 3.91 to 26.86 cmol (p^+) Kg^{-1}. This wide variation of ECEC value might be due to the variation of clay content in the study area (Kalshetty *et al.*, 2012). The ECEC found to be increased with increasing clay content and pH. The highest mean value of ECEC was recorded from Thirunelly (11.22 cmol (p^+) Kg^{-1}) where high clay content (33.78 %), available Ca (886.67 mg kg^{-1}) and available Mg (486.67 mg kg^{-1}) were also observed. The strong positive correlation between CEC, pH and clay content is consistent with previous studies in several regions (Olorunfemi *et al.*, 2016; Sulieman *et al.*, 2018). ECEC showed a significant negative correlation with per cent of sand content in soil. Most of the soils (94%) had ECEC value between 5 and 16 cmol (p^+) Kg^{-1} (Fig. 36).

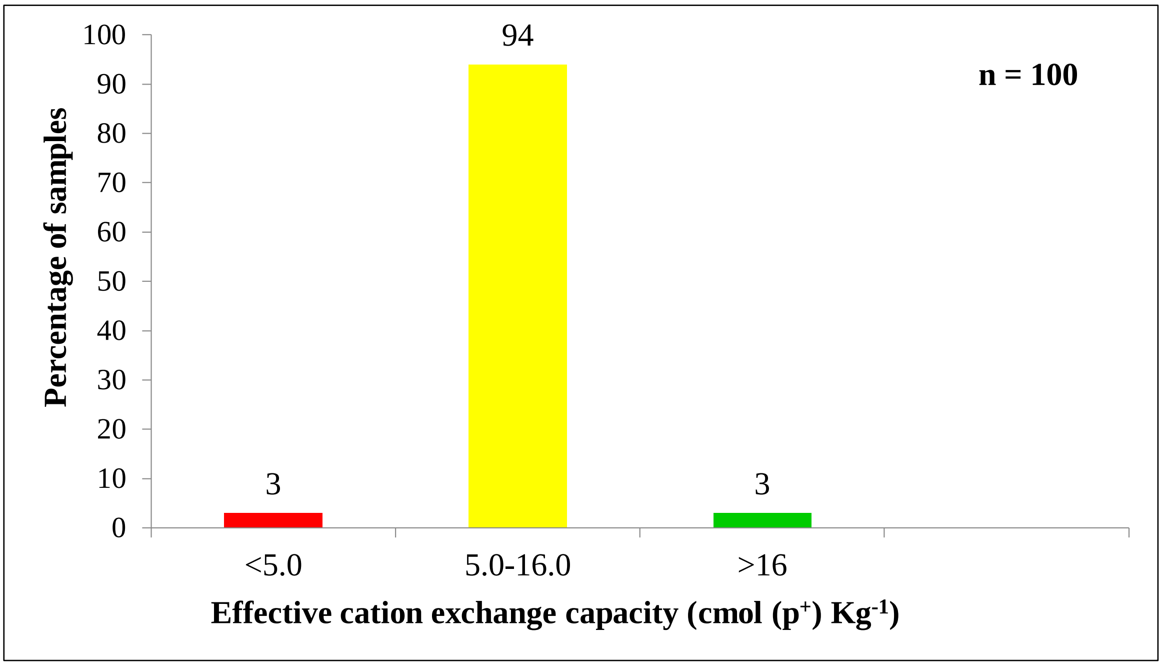

Fig. 36. Frequency distribution of effective cation exchange capacity in the post-flood soils of Mananthavady block in Wayanad district

5.1.3. Biological attributes

5.1.3.1. Acid phosphatase activity

The activity of acid phosphatase of post flood soils of Mananthavady block ranged from 11.90 µg PNP produced g soil^{-1} h^{-1} (Thirunelly) to 58.78 µg PNP produced g soil^{-1} h^{-1} (Edavaka). Acid phosphatase activity was significantly positively correlated with organic carbon and significantly negatively correlated with pH. As the soil pH increases the activity of acid phosphatase enzyme decreases (Dick *et al.,* 2000). Acid phosphatase activity releases more phosphate from acidic soil and the content of available P is increased. About 37% in the range of 10 µg PNP produced g soil^{-1} h^{-1} to 25 µg PNP produced g soil^{-1} h^{-1}, 61% in the range of 25 µg PNP produced g soil^{-1} h^{-1} to 50 µg PNP produced g soil^{-1} h^{-1} and 2% greater than 50 µg PNP produced g soil^{-1} h^{-1} (Fig 37).

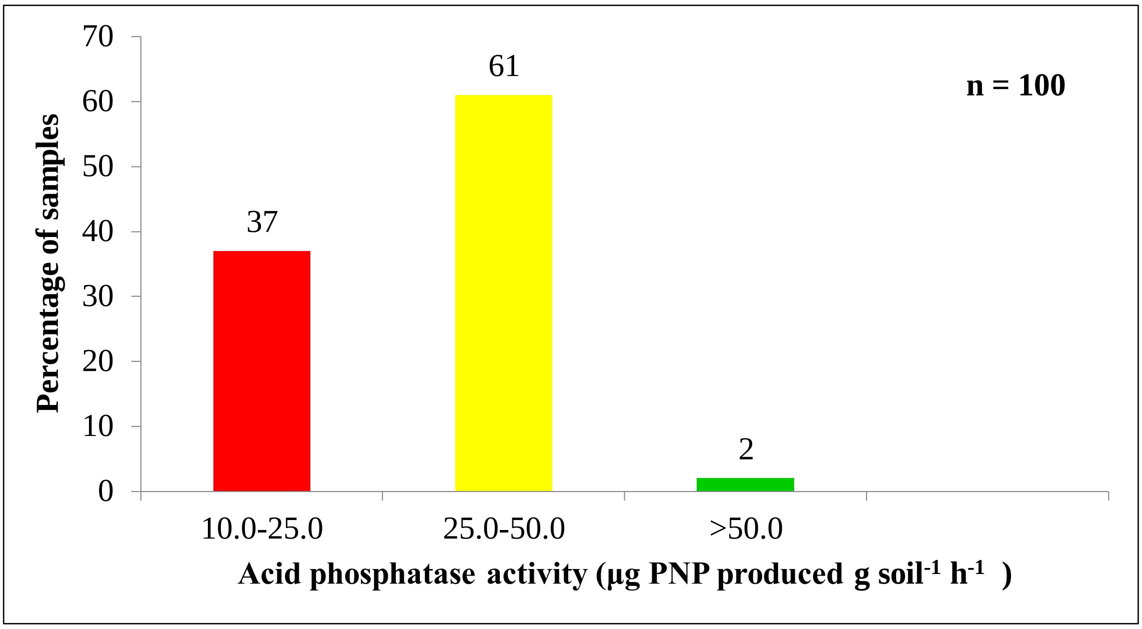

Fig. 37. Frequency distribution of acid phosphatase activity in the post-flood soils of Mananthavady block in Wayanad district

5.2. SOIL QUALITY INDEX

A weighted soil quality index was calculated using a minimum data set of parameters obtained from principal component analysis. A minimum data set of ten parameters were identified out of 23 analysed parameters and the MDS consist of ECEC, pH, percent silt, organic carbon, available K, available B, available S, available Fe, available P, and available Zn. Relative soil quality index was developed from the calculated SQI and based on RSQI, the soils were rated as poor (<50%), medium (50%-70%) and good (>70%) (Kundu *et al*., 2012). Medium soil quality was obtained for 73% of samples followed by 24% good and 3% poor (Fig. 38). The soil quality index was found predominantly lower in areas with low level of organic carbon, available potassium and very low levels of available nitrogen and sulphur. The highest mean of RSQI was observed in Thondernadu (68.43%) where highest mean of organic carbon (1.73%), available N (243.50 kg ha^{-1}) and K (251.82 kg ha^{-1}) and sufficient level of available Ca, Mg, Fe, Mn, Zn, and Cu are recorded. Whereas the highest value of RSQI was recorded from Vellamunda (86%) where high content of organic carbon, available phosphorous, potassium, calcium, and magnesium and sufficient level of micro nutrients and slightly acidic pH were observed. Spatial distribution of soil quality is depicted in Fig. 39.

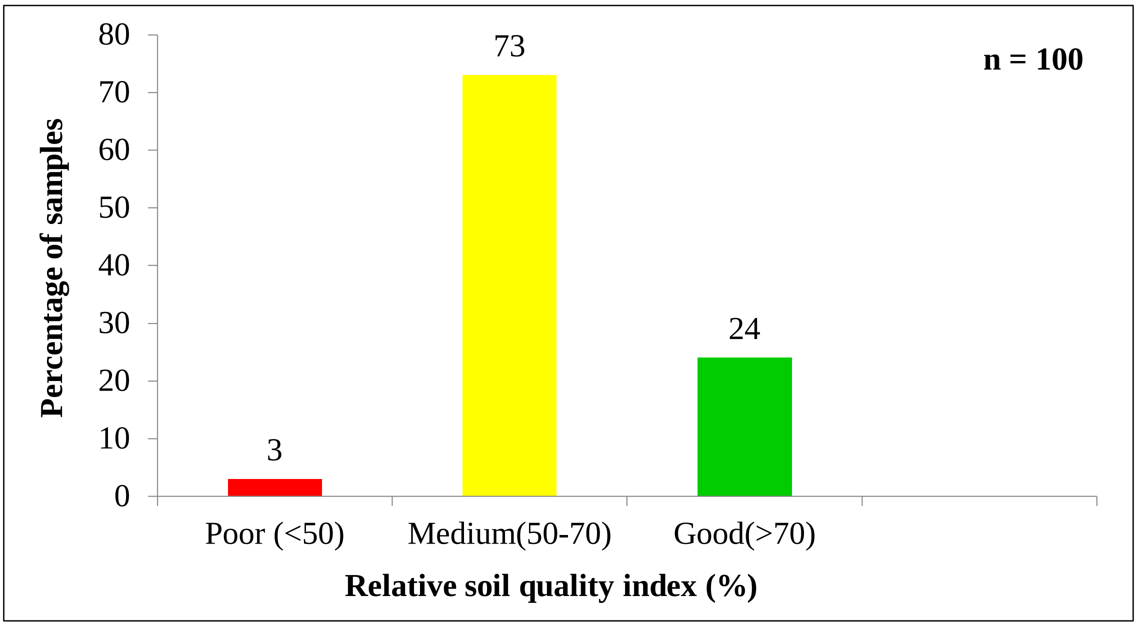

Fig. 38. Frequency distribution of RSQI in the post-flood soils of Mananthavady block in Wayanad district

5.3. NUTRIENT INDEX

Nutrient index at panchayath level was worked out for organic carbon, available nitrogen, phosphorous and potassium. The spatial distributions of nutrient indices are depicted in Fig. 40, 41, 42, and 43. Nutrient index for organic carbon was medium for all the panchayaths except for Thondernadu panchayath which has high nutrient index (2.71). Nutrient index for available nitrogen was low in all panchayaths. Nutrient index for available phosphorous was high in Mananthavady, Edavaka, Thirunelly, and Thavinhal panchayaths and was medium in other panchayaths. Nutrient index for potassium was medium in all panchayats except Thirunelly and Edavaka as they had low fertility status for potassium.

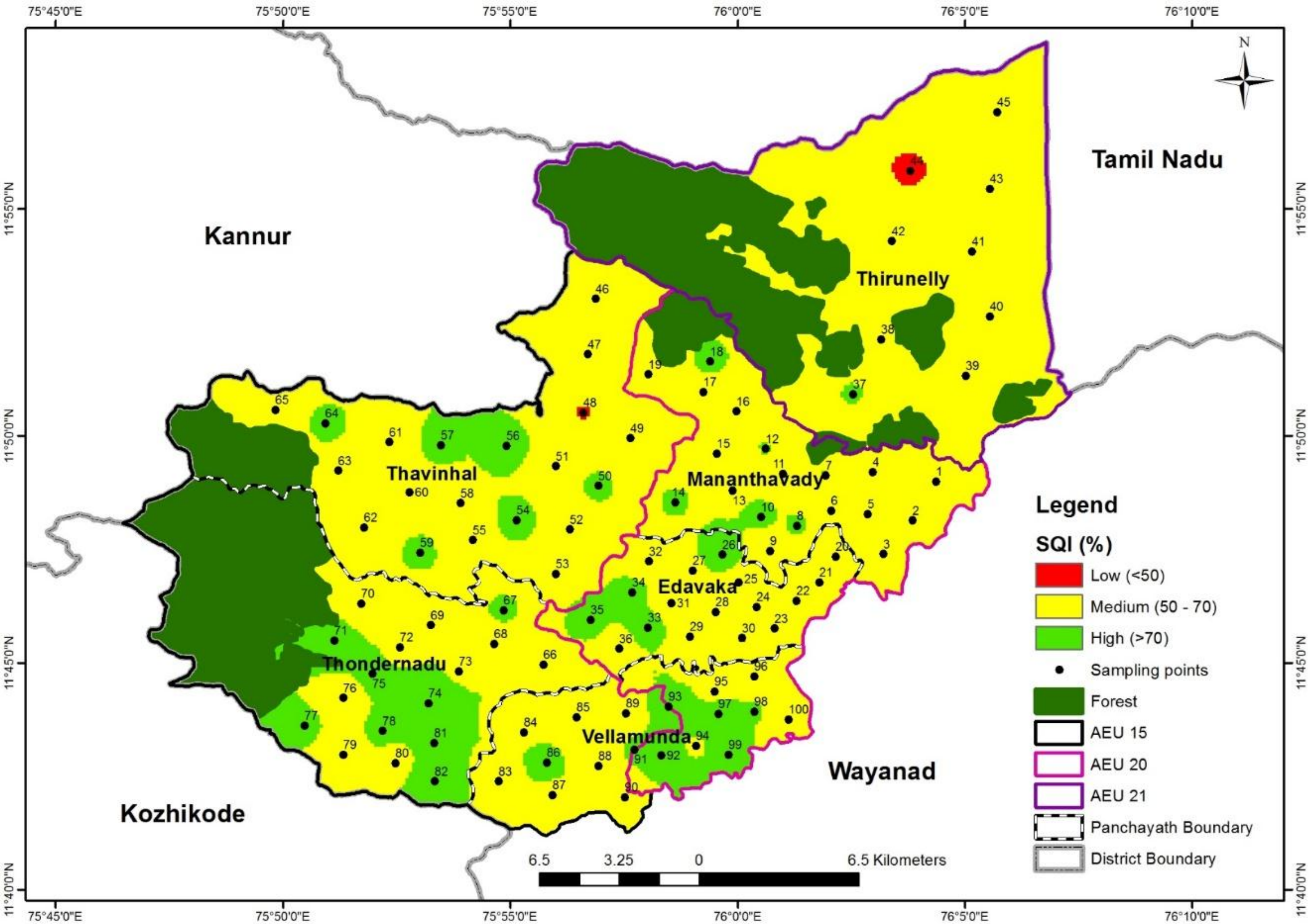

Fig. 39. Spatial variation of SQI in post-flood soils of Mananthavady block in Wayanad district

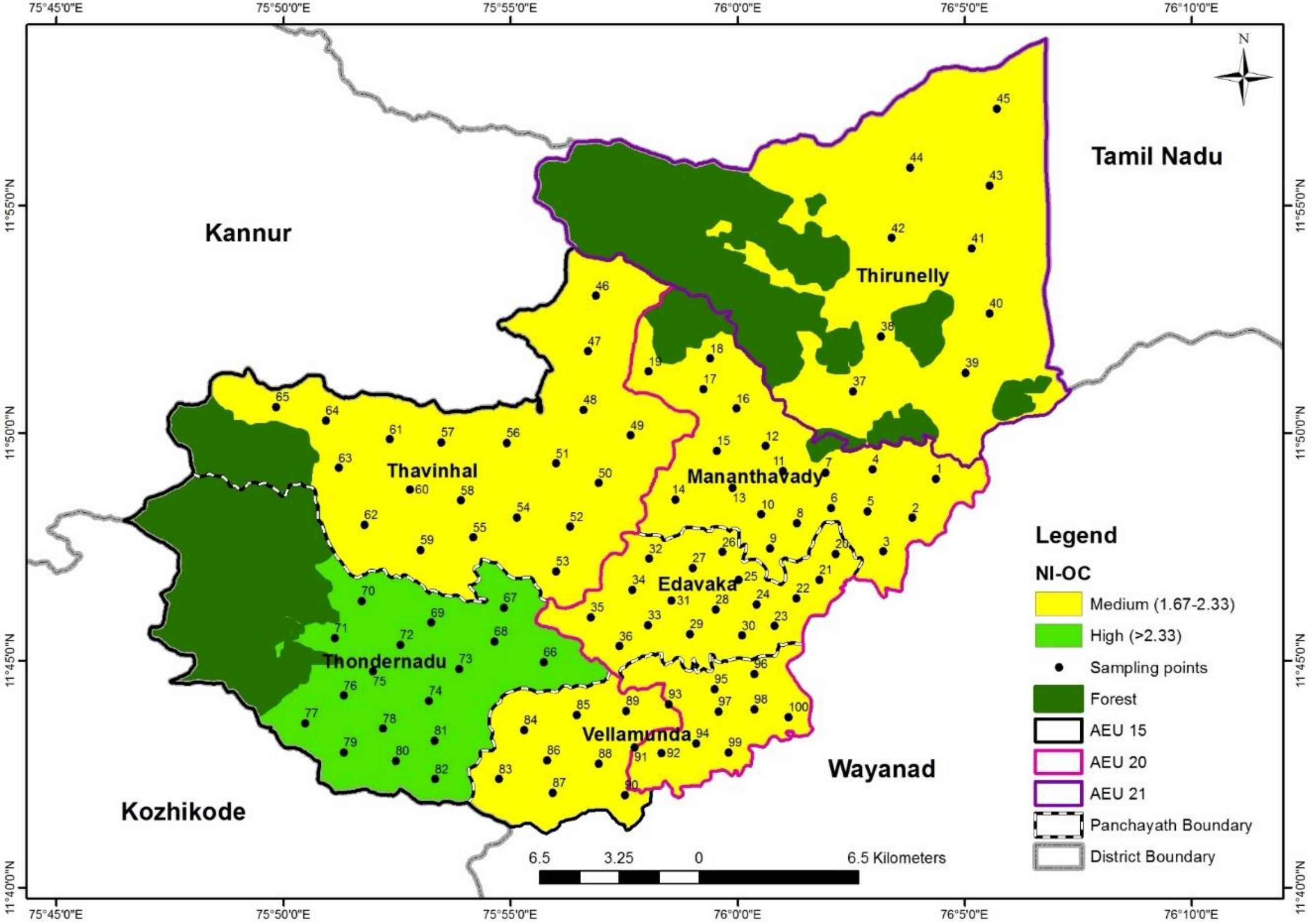

Fig. 40. Spatial variation of NI- OC in post-flood soils of Mananthavady block in Wayanad district

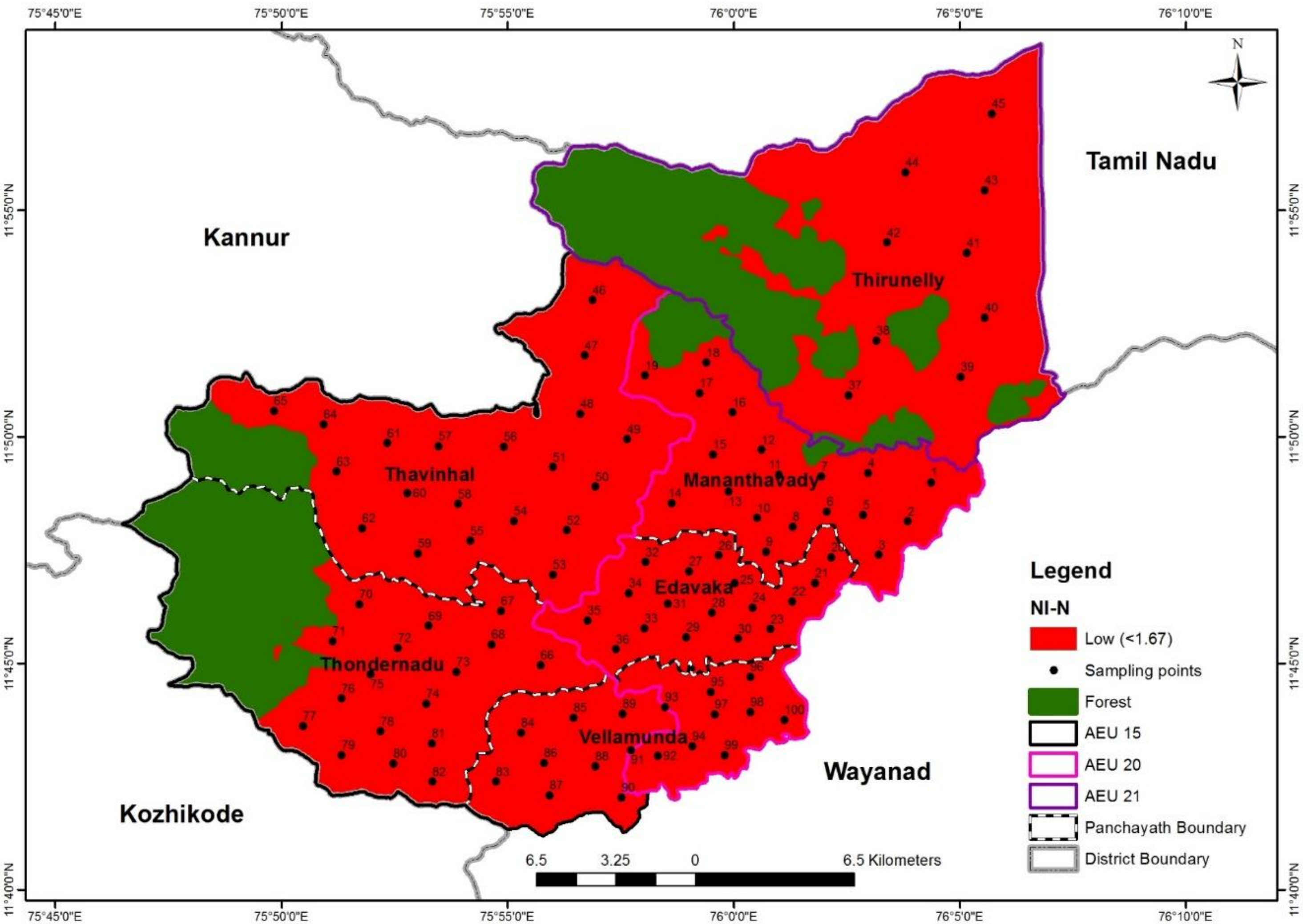

Fig. 41. Spatial variation of NI-N in post-flood soils of Mananthavady block in Wayanad district

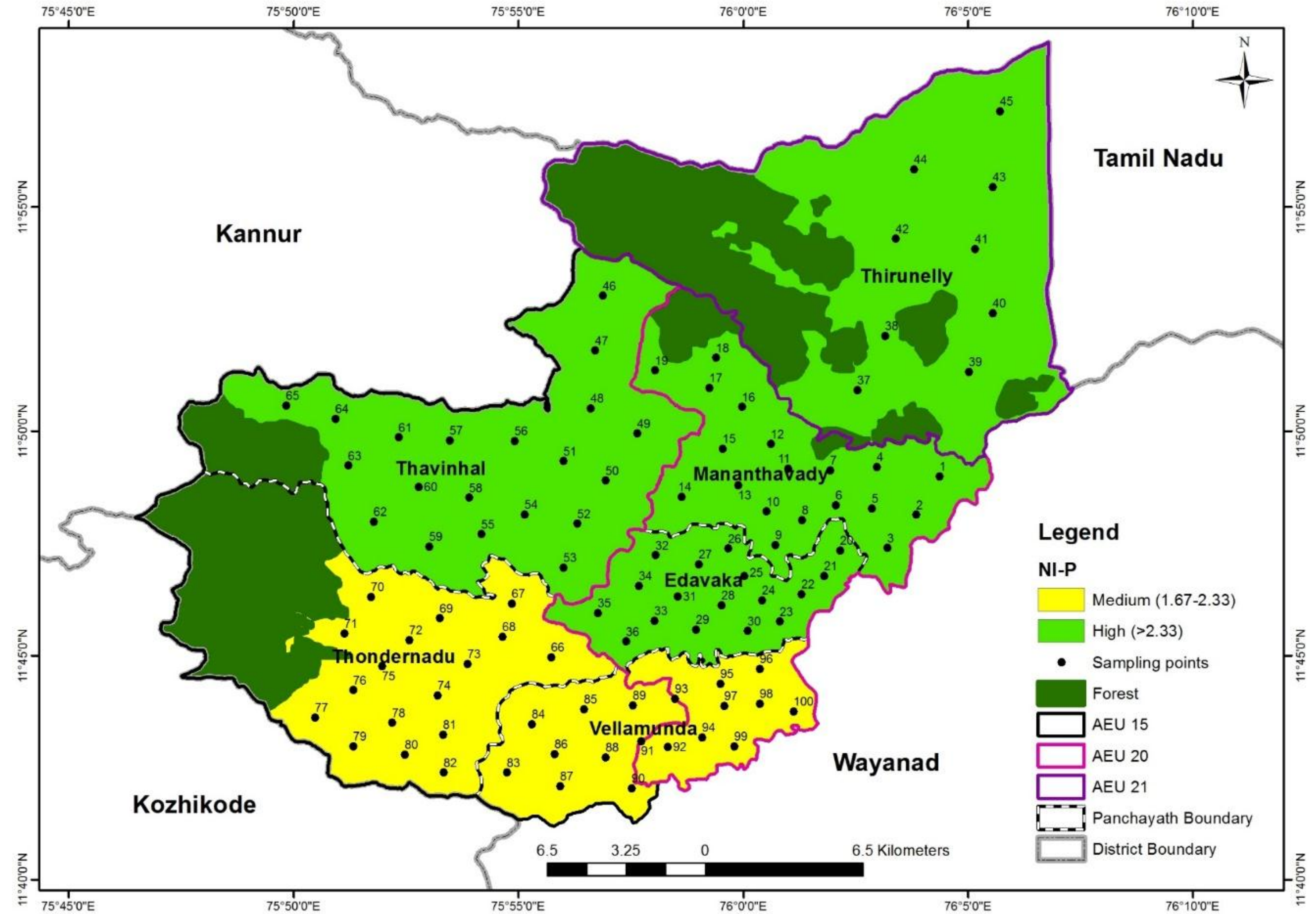

Fig. 42. Spatial variation of NI-P in post-flood soils of Mananthavady block in Wayanad district

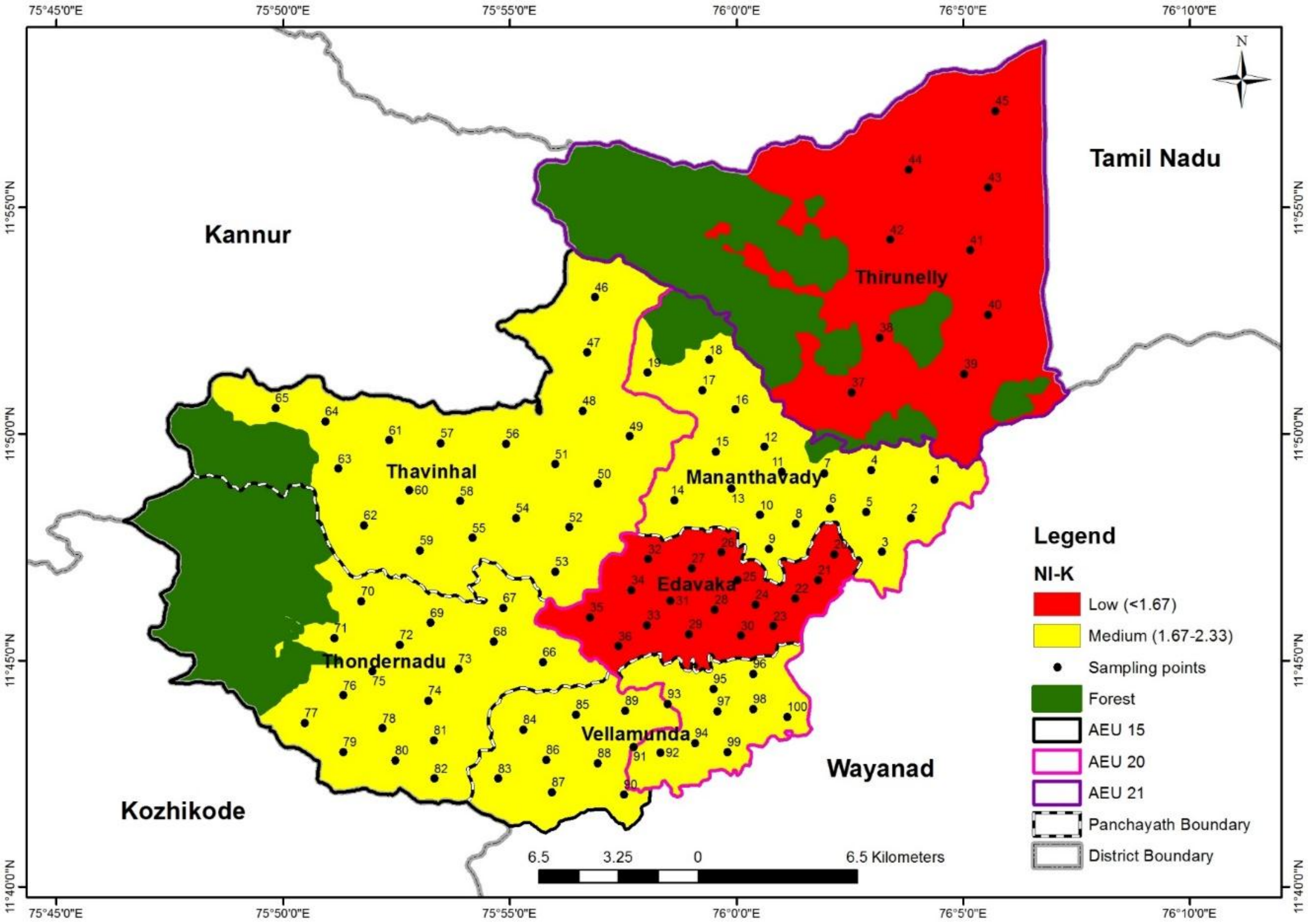

Fig. 43. Spatial variation of NI-K in post-flood soils of Mananthavady block in Wayanad district

5.4. LAND QUALITY INDEX

Land quality index was developed based on soil organic carbon stock which is calculated using soil organic carbon, bulk density and soil depth. LQI was very low (< 3 kgm^{-2}) in 69% of soils, low (3-6 kgm^{-2}) in 30% and medium (6-9 kgm^{-2}) in 1% of soils (Fig. 44). The soil organic carbon stock varied between 0.59 kgm^{-2} and 6.79 kgm^{-2}. Spatial distribution of LQI in flood affected soils of Mananthavady block is depicted in Fig. 45. The highest mean of 3.35 kgm^{-2} SOC was reported from foot hill region represented by Thondernadu and lowest mean (1.55 kgm^{-2}) was observed from hill region represented by Thirunelly panchayath. Majority of the area had very low to low land quality. The lowest land quality was found in the region where the organic carbon status was low due to high erosion, steep slope and light soil texture (Anil Kumar *et al*., 2015).

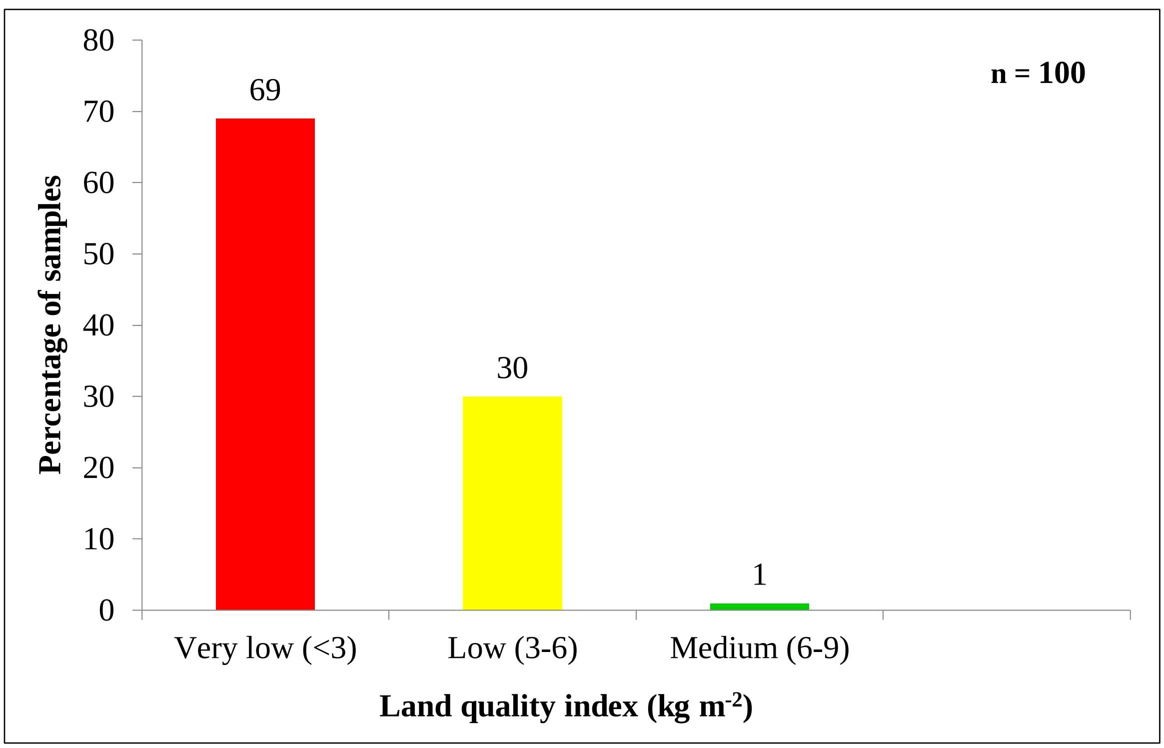

Fig. 44. Frequency distribution of Land quality index in the post-flood soils of Mananthavady block in Wayanad district

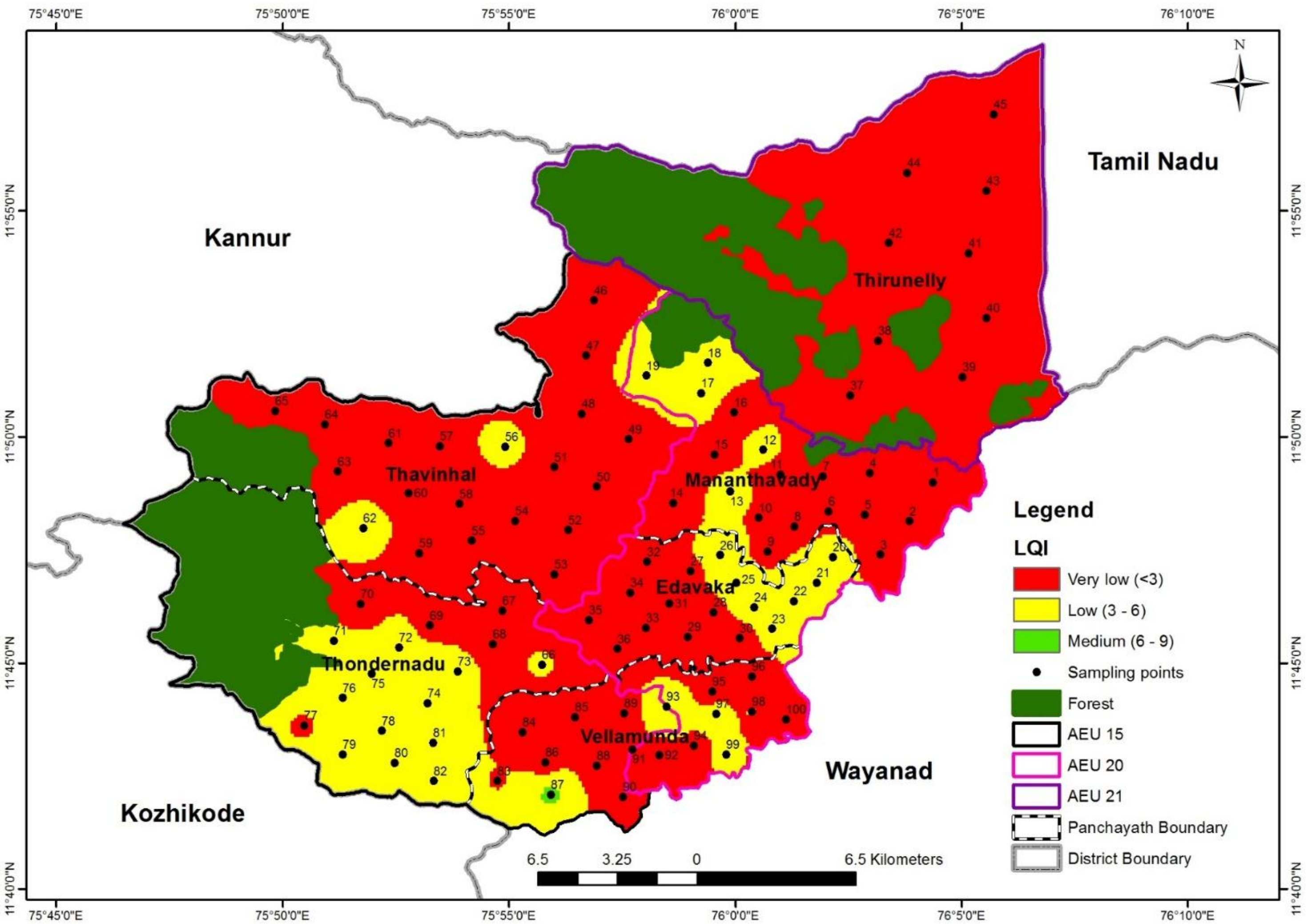

Fig. 45. Spatial variation of LQI in post flood soils of Mananthavady block in Wayanad district

5.5. COMPARISON OF PRE AND POST- FLOOD SOILS OF MANANTHAVADY BLOCK IN WAYANAD DISTRICT

Mananthavady block was severely affected by the flood and associate landslides which happened in the year 2018. Mananthavady, Thavinhal, Thondernadu, and Thirunelly were the worst affected regions followed by Vellamunda and Edavaka. Soil reaction, organic carbon content and nutrients were compared with the pre flood data of KSPB (2013) (Appendix IV). Samples with extremely acid and moderately acid soil reaction were decreased by 11% whereas samples with very strongly acid and strongly acid were increased by 18 and 3% respectively after the occurrence of flood. A decrease in organic carbon status of the soil was observed after the flood. Organic carbon status decreased from 55% in pre flood to 31% in post flood in high category. On the other hand it increased from 35% to 61% in medium category. This can be attributed to the erosion of organic matter rich surface soil layer and leaching of organic acids and humus from hilly region and their deposition in foot hills.

The available phosphorus in soil was observed to be increased after the occurrence of flood. There was no sample in low category in post flood compared to 31% in pre flood and there was a sharp increase in percentage of soils under medium category of P after flood from 20% to 56%. The available potassium in soil was found to be decreased in post flood soil. A decline was observed in the percent of samples medium in available K from 59% to 41% in the post-flood study and percentage of samples belonging to the low category was increased by 12%. Decline in available K indicates leaching of nutrients in the area.

In case of available calcium and magnesium, there was a sharp increase in percentage of samples under sufficient level in after the occurrence of flood. The sufficient level of calcium increased from 34 to 87% and that of magnesium increased from 38 to 93% in post flood soil as compared to pre flood. Available sulphur was sufficient for only 15% of samples in the post-flood study compared to 36% in the pre flood scenario indicating decrease in available sulphur.

An increase was observed in samples with adequate available zinc from 53% in the pre flood study to 100% in the post-flood study. Percentage samples with adequate level available copper were increased form 65% to 73% after the occurrence of flood. Boron was deficient in 100% of the samples in post flood whereas it was deficient in 93% in pre flood scenario.

In general, available P, Ca, Mg, Zn, and Cu status improved in the post-flood soils whereas organic carbon, available K, S, and B status deteriorated compared to the pre flood data.

5.6. SUGGESTED INTERVENTIONS IN OF MANANTHAVADY BLOCK IN WAYANAD DISTRICT

The major land uses in Mananthavady block of Wayanad district are banana, paddy, coffee, pepper, vegetables, arecanut, and coconut. The physicochemical attributes of the post flood soil have shown the variations in the status of pH, organic carbon and nutrients. For successful crop production it is necessary to bring changes in crop production strategies according to the status of soil after the flood.

Soil pH was extremely acidic to very strongly acidic in large parts of Thavinhal, Thonderndu, Vellamunda, Edavaka, Mananthavady and some parts of Thirunelly demanding an elevation in the quantity of liming materials to be applied and a change in the schedule of liming. Soil pH was strongly acid to moderately acid in larger part of Thirunelly and some parts of Vellamunda, Edavaka, Mananthavady and Thavinhal indicating lesser lime requirement.

Medium organic carbon content in most the study area necessitate an increase in the quantity of organic manure applied to the soils. The low available nitrogen content in flood affected soils demands the application of nitrogenous fertilizers as per package of practices recommendations of KAU (2016) along with organic manures. Application of phosphatic fertilizers can be reduced since available P was high in most of the area. Decline in available K status was observed in post-flood soils necessitating an incorporation of potassium sources to the soils. Available S status showed a decrease in the post-flood soils which can be corrected through application of nitrogenous fertilizers like ammonium sulphate and complex fertilizers like factamphos. The hundred per cent deficiency of available B in the study area highly demands the application of boron fertilizers like borax or solubor either as soil application or as foliar spray. Proper soil conservation measures along with practices to increase the use efficiency of fertilizers have to be adopted as the study area is highly vulnerable to erosion and leaching losses. Adopting such management practices can improve soil health and hence crop productivity of the post flood soils of Mananthavady block in Wayanad district.

Summary

6. SUMMARY

The present study entitled “Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district” was done with the objective to assess the soil quality of post-flood soils of Mananthavady block in Wayanad district, to develop maps on soil characters using GIS techniques and to work out soil quality index (SQI). For this purpose a survey was conducted in the study area.

Geo-referenced soil samples were collected for analysis, from the flood affected panchayaths of the Mananthavady block. Using the Principle Component Analysis (PCA) technique for feature extraction, a dimensionality reduction of the initial dataset resulted in Minimum Data Set (MDS) containing 10 most prominent attributes *viz.*, ECEC, pH, percent silt, organic carbon, available K, available B, available S, available Fe, available P, and available Zn.

The identified soil quality indicators were grouped into four classes *viz.*, very poor, poor, good and very good and given with scores of 1, 2, 3 and 4 respectively. Computation of weighted Soil Quality Index (SQI) was performed after assigning appropriate weight to each parameter. The study area was then categorized into poor, medium and good using the Relative Soil Quality Index (RSQI) value.

Panchayath-wise nutrient indices were estimated for organic carbon and available primary nutrients (N, P and K). Based on soil organic carbon stock, the Land Quality Index (LQI) was estimated and thematic maps were prepared for the various soil parameters using the ArcGIS v10.3 software. Correlation between physical, chemical and biological parameters was computed in terms of Pearson’s Correlation Coefficient (PCC). Salient findings of the study are summarized below:

- The lowest and highest mean values of bulk density at 15cm were observed for Edavaka (1.24 Mg m^{-3}) and Thirunelly (1.41 Mg m^{-3}).
- The highest mean value of particle density of 2.42 Mg m^{-3} and porosity of 47.85% were noticed in Mananthavady municipality and Edavaka panchayath respectively.

- Sediment deposits of coarser and finer material with varying thickness were found in various parts of block. Sandy clay loam was the predominant soil texture observed in 60% of the study area followed by clay loam (17%) and sandy loam (14%).
- The maximum water holding capacity varied between 32.57% and 64.10% with a mean value of 46.90%.
- Majority of soils had bulk density between 1.4 to1.6 Mg m^{-3} (61%), particle density between 2.2 to 2.4 Mg m^{-3} (50%), porosity between 30-50% (85%), and maximum water holding capacity between 30 to 50% (70%).
- Soil pH varied between 3.71 and 6.03 with a mean value of 4.86. About 20% of the soils were extremely acidic (3.51-4.5), 47% very strongly acidic (4.5-5.5), 25% strongly acidic (5.0-5.5) and 7% moderately acidic (5.5-6.0). Majority (77%) of the soils had exchangeable acidity between 0.55 to 6.96 cmol (p^+) Kg^{-1}. Electrical conductivity was less than 1 dSm^{-1} all over the study area.
- Thondernadu recorded the highest mean value of organic carbon (1.73%), available nitrogen (243.50 kg ha^{-1}) and potassium (251.82 kg ha^{-1}) and the Thirunelly panchayath recorded lowest mean value for above three parameters.
- Organic carbon status was medium for 61% and high for 31% of the soils. Majority (94%) of the soils were low in available N status. About 41% of the soils were rated as medium and 37% of the soils were rated as low in available K content.
- The available P was the highest in Mananthavady municipality (45.06 kg ha^{-1}) and the lowest in Vellamunda (21.76 kg ha^{-1}). Available P content was rated high for 44% and medium for 56% of the soils.
- Thirunelly recorded the highest mean value for available Ca (886.67 mg kg^{-1}) and Mg (486.67 mg kg^{-1}) and Vellamunda registered the highest mean of available S (4.18 mg kg^{-1}). Thavinhal panchayath recorded the lowest mean value for available Ca, Mg and S. Sufficient amounts of Ca (87%), and Mg (93%) were available whereas S (85%) was deficient in majority of the soils.

- The highest mean of available Fe (117.89 mg kg^{-1}), Mn (71.08 mg kg^{-1}), Zn (8.45 mg kg^{-1}) and B (0.10 mg kg^{-1}) were observed from the Mananthavady municipality whereas Thondernadu recorded the highest mean for available Cu (4.71mg kg^{-1}). 100% of the samples were sufficient in available Fe, Mn, Zn and were deficient in available B. Available Cu was sufficient for 73% of the soil in the study area.
- Majority (96%) soils had low level of exchangeable Na and it varied between 0.12 cmol Kg^{-1} and 0.43 cmol Kg^{-1} in the study area. Exchangeable Al ranged from 0.50 to 6.72 cmol Kg^{-1} and about 49% of the soils had exchangeable Al between 2 and 4 cmol Kg^{-1}. Effective cation exchange capacity varied between 3.91 and 26.86 cmol (p^+) Kg^{-1}in the post-flood area of Mananthavady block in Wayanad district and Thirunelly recorded the highest mean value for ECEC (11.22 cmol (p^+) Kg^{-1}).
- Majority (61%) of soils had acid phosphate activity in the range of 25 to 50 µgm PNP produced/gram soil/hr.
- Relative SQI ranged from 43.50% to 86.00% with a mean value of 64.88 %. Soil quality was observed to be higher in Thondernadu which had also recorded relatively higher organic carbon, available N and K and had sufficient level of available Ca, Mg, Fe, Mn, Zn, and Cu. About 73% of soils were rated as medium and 24% of the soils were high in soil quality.
- Nutrient index for organic C was high in Thondernadu panchayath and it was medium for all other panchayths. Nutrient index for available N was low in the entire study area. Nutrient index for available P was high in Mananthavady, Edavaka, Thirunelly, and Thavinhal panchayaths and medium in Thondernadu, and Vellamunda panchayaths. Nutrient index for K was medium in all panchayaths and low in Thirunelly and Edavaka.
- Soil organic carbon stock ranged between 0.59 kg m^{-2} and 6.79 kg m^{-2}in the study area. The highest value was observed in Thondernadu (3.35 kg m^{-2}) where high organic carbon content was observed. LQI was very low (<3 Kg m^{-2}) in 69%, low (3-6 Kg m^{-2}) in 31% and medium (6-9 Kg m^{-2}) in 1% of the soils.

Soil reaction, organic carbon content and nutrients were compared with the pre-flood data of KSPB (2013). This comparison revealed that extremely acidic and moderately acidic soil samples decreased by 11% whereas very strongly acidic samples increased by 18% in post flood soil. Organic carbon in high status decreased after the floods from 55% to 31%. There was a sharp increase in percentage of soils under medium category of P in post flood soil from 20% to 56%. A decline was observed in the percent of samples medium in available K from 59% to 41% and percentage of samples belonging to the low category was increased by 12% after the flood. Sufficient levels of available Ca, Mg, Zn, and Cu was higher after the flood whereas there was a decline of soils adequate in available S and B.

The present study indicates an alteration in soil conditions and nutrient status in the Mananthavady block of Wayanad district after the 2018 floods. The flood has a beneficial impact on the availability of P, Ca, Mg, Zn and Cu content of the soil, whereas it has negatively affected the organic C content and availability of K, S and B in the study area. Hence, this study demands a revision of existing cropping systems and soil management practices, on the basis of altered soil status, to enhance and achieve higher quality in productivity and sustainability.

References

7. REFERENCES

Abdelrahman, M. A. E., Natarajan, A., Srinivasamurthy, C. A., and Hegde, R. 2016. Estimating soil fertility status in physically degraded land using GIS and remote sensing techniques in district, Karnataka, India. *Egypt. J. Remote Sens. Space Sci.* 19(1): 95-108.

Abreu Jr, C.H., Muraoka, T., and Lavorante, A.F. 2003. Relationship between acidity and chemical properties of Brazilian soils. *Scientia Agricola*, 60(2): 337-343.

Adeboye, M. K. A., Bala, A., Osunde, A. O., Uzoma, A. O., Lawal, B. A. and Odofin, A. J. 2011. Assessment of soil quality using soil organic carbon and total nitrogen and microbial properties in tropical agroecosystems. *Agric. Sci.* 2(1): 34-40.

Akpoveta, V. O., Osakwe, S. A., Ize-Iyamu, O. K., Medjor, W. O., and Egharevba, F. 2014. Post flooding effect on soil quality in Nigeria: the Asaba, Onitsha experience. *Open J. Soil Sci.* 12: 13-19.

Ali, M.E., El-Hussieny, O.H.M., Rashed, H.S.A., Mohamed, E.S., and Salama, O.H.E. 2015. Assessment of Soil Quality Using Remote Sensing and GIS Techniques in Some Areas of North-East Nile Delta, Egypt. *Egypt J. Soil Sci*. 55(1): 621-638.

Alkorta, I., Aizpurua, A., Riga, P., Albizu, I., Amezaga, I., and Garbisu, C. 2003. Soil enzyme activities as biological indicators of soil health. *Rev. Environ. Health* 18(1): 65-73.

Amacher, M. C., O'Neil, K. P., and Perry, C. H. 2007. *Soil Vital Signs: A New Soil Quality Index (SQI) for Assessing Forest Soil Health.* US Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. 12p. Available: http://www.fs.fed.us/rm/pubs/rmrs_rp 065 .pdf. [07 May 2020].

Andrews, S. S. and Carroll, C. R. 2001. Designing a soil quality assessment tool for sustainable agro ecosystem management. *Ecol. Appl.* 11(6): 1573-1585.

Andrews, S. S., Karlen, D. L., and Cambardella, C. A. 2004. The soil management assessment framework: a quantitative soil quality evaluation method. *Soil Sci. Soc. Am. J*. 68(6): 1945-1962.

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

Anil Kumar, K. S., Lalitha, M., Kalaiselvi, B., Patil, S., Nair, K.M., and Sujatha, K. 2015. Soil organic carbon stocks: a potential land quality indicator for soils of Western Karnataka. *Agropedology*, 25(02): 161-168.

Aparicio, V. and Costa, J.L. 2007. Soil quality indicators under continuous cropping systems in the Argentinean Pampas. *Soil Tillage Res. 96*(1-2): 155-165.

Armenise, E., Redmile-Gordon, M. A., Stellacci A. M., Ciccarese, A. and Rubino, P. 2013. Developing a soil quality index to compare soil fitness for agricultural use under different managements in the Mediterranean environment. *Soil Tillage Res.* 130: 91–98.

Arshad, M. A. and Coen, G. M. 1992. Characterization of soil quality: physical and chemical criteria. *Am. J. Altern. Agric*. 1: 25-31.

Arshad, M. A. and Martin, S. 2002. Identifying critical limits for soil quality indicators in agroecosystems. *Agric. Ecosyst. Environ.* 88(2): 153-160.

Asadi, H., Moussavi, A., Ghadiri, H., and Rose, C.W. 2011. Flow-driven soil erosion processes and the size selectivity of sediment. *J. Hydrol.* 406(1-2): 73-81.

Askari, M.S. and Holden, N.M. 2014. Indices for quantitative evaluation of soil quality under grassland management. *Geoderma,* 230: 131-142.

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

Basak, N., Datta, A., Mitran, T., Roy, S.S., Saha, B., Biswas, S., and Mandal, B. 2016. Assessing soil-quality indices for subtropical rice-based cropping systems in India. *Soil Res.* 54(1): 20-29.

Batjes, N. H. 1996. Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* 47(2): 151-163.

Behara, S. K. and Shukla, A. K. 2014. Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content and exchangeable potassium, calcium and magnesium in some cropped acid soils of India. *Land Degradation Dev.* 26: 71-79.

Beinroth, F. H., Eswaran, H., and Reich, P. F., 2001. Global assessment of land quality. In: *Sustaining the Global Farm.* International Soil Conservation Organization, Agricultural Research Service, and National Soil Erosion Research Laboratory and Purdue University, pp. 569–574.

Bhaduri, D., Purakayastha, T. J., Patra, A. K., and Chakraborty, D. 2014. Evaluating soil quality under a long-term integrated tillage-water-nutrient experiment with intensive rice-wheat rotation in a semi-arid Inceptisol, India. *Environ. Monitoring Assess*. 186(4): 2535-2547.

Bhattacharyya, R., Ghosh, B.N., Mishra, P.K., Mandal, B., Rao, C.S., Sarkar, D., Das, K., Anil, K.S., Lalitha, M., Hati, K.M., and Franzluebbers, A.J. 2015. Soil degradation in India: Challenges and potential solutions. *Sustainability, 7*(4): 3528-3570.

Bingham, F. T. 1982. Boron. In: Page, A. L. (ed.), *Methods of soil analysis* (2^{nd} ed.). *Am. Soc. of Agron*. Madison, USA, 438p.

Blake, G. R. 1965. Bulk density. In: Black, C. A., Evans, D. D., Ensminger, L. E., White, J. L., and Clark, F. E. (eds), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling.* American Society of Agronomy Inc., Madison, USA, pp. 374-390.

Bongiorno, G., Bunemann, E.K., Oguejiofor, C.U., Meier, J., Gort, G., Comans, R., Mader, P., Brussaard, L., and de Goede, R. 2019. Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. *Ecological Indicators, 99*: 38-50.

Bouma, J. 2000. The land quality concept as a means to improve communication about soils. In: Elmholt, S., Stenberg, B., Gronlund, A. and Nuutinen, V. (eds), *Soil Stresses, Quality and Care*. Proceedings of the NJF Seminar 310, Elmholt, Norway. Danish Institute of Agricultural Sciences, Denmark, pp. 1-14.

Brandao, M., i Canals, L.M., and Clift, R. 2011. Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass Bioenergy, 35*(6):2323-2336.

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

Bredja, J. J., Moorman, T. B., Karlen, D. L., and Dao, T. H. 2001. Identification of regional soil quality factors and indicators: I. Central and southern high plains. *Soil Sci. Soc. Am. J.* 64(6): 2115-2124.

Bunemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., and Pulleman, M. 2018. Soil quality–A critical review. *Soil Biol. Biochem. 120*:105-125.

Buragohain, S., Sarma, B., Nath, D.J., Gogoi, N., Meena, R.S., and Lal, R. 2018. Effect of 10 years of biofertiliser use on soil quality and rice yield on an Inceptisol in Assam, India. *Soil Res. 56*(1): 49-58.

Burger, J. and Kelting, D. 1998. Soil quality monitoring for assessing sustainable forest management. In: Adams, M. B., Ramakrishna, K., and Davidson, E. (eds), *The Contribution of Soil Science to the Development of and Implementation of Criteria and Indicators of Sustainable Forest Management*. Soil Science Society of America Publication, Madison, USA, pp. 17-52.

Burrough, P. A. and Mc Donnell, R. A. 1998. *Principles of Geographic Information Systems*. Oxford University Press, New York, 270p.

Cardoso, E.J.B.N., Vasconcellos, R.L.F., Bini, D., Miyauchi, M.Y.H., Santos, C.A.D., Alves, P.R.L., Paula, A.M.D., Nakatani, A.S., Pereira, J.D.M., and Nogueira, M.A. 2013. Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? *Scientia Agricola*, *70*(4): 274-289.

Carter, M. R., Andrews, S. S., and Drinkwater, L. E. 2004. Systems approaches for improving soil quality. In: Schjonning, P., Elmholt, S. and Christensen, B. T. (eds), *Managing Soil Quality: Challenges in Modern Agriculture*. CABI International, Wallingford, UK, pp. 261–281.

Carter, M. R., Gregorich, E. G., Anderson, D. W., Doran, J. W., Janzen, H. H., and Pierce, F. J. 1997. Concepts of soil quality and their significance. *Dev. Soil Sci.* 25: 1–19.

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

CTCRI [Central Tuber Crops Research Institute]. 2018. *Post-flood loss assessment and rehabilitation of tuber crops in Kerala*. Central Tuber Crops Research Institute (Indian Council of Agricultural Research) Sreekariyam, Thiruvanathapuram. 103p.

Dagnachew, M., Moges, A., Kebede, A. and Abebe, A. 2020. Effects of Soil and Water Conservation Measures on Soil Quality Indicators: The Case of Geshy Subcatchment, Gojeb River Catchment, Ethiopia. *Appl. Environ. Soil Sci.* 2020: 1-16.

Dakshinamurthi, C. and Gupta, R. P. 1968. *Practicals in Soil Science*. I.A.R.I, New Delhi, 210p.

Danielson, R. E. and Sutherland, P. L. 1986. Porosity. In: Klute, A. (ed.), *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods*. American Society of Agronomy, Madison. pp. 443-461.

Das, S. K. and Varma, A. 2010. Role of enzymes in maintaining soil health. In: Shukla, G. and Varma, A. (eds), *Soil Enzymology*. Springer, Berlin, Heidelberg, pp. 25-42.

de Andrade Barbosa, M., de Sousa Ferraz, R.L., Coutinho, E.L.M., Neto, A.M.C., da Silva, M.S., Fernandes, C., and Rigobelo, E.C. 2019. Multivariate analysis and modeling of soil quality indicators in long-term management systems. *Sci. Total Environ.* 657: 457-465.

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

De la Rosa, D. and Sobral, R. 2008. Soil quality and methods for its assessment. In: Braimoh and Vlek (eds), *Land Use and Soil Resources*, Springer, Netherlands, pp.167-200.

Denis, M. K. A., Parameshgouda, L. P., Augustine, M. K., and Daniel, H. S. 2017. Assessment of soil fertility status using nutrient index approach. *Acad. J. Agric. Res.* 5(2): 28-38.

Dick, W.A., Cheng, L. and Wang, P., 2000. Soil acid and alkaline phosphatase activity as pH adjustment indicators. *Soil Biol. Biochem.* 32(13): 1915-1919.

Diodato, N. and Ceccarelli, M. 2004. Multivariate indicator Kriging approach using a GIS to classify soil degradation for Mediterranean agricultural lands. *Ecological Indicators* 4(3): 177-187.

do Nascimento, D.M., Cavalieri-Polizeli, K.M.V., da Silva, A.H., Favaretto, N. and Parron, L.M., 2019. Soil physical quality under long-term integrated agricultural production systems. *Soil Tillage Res. 186*: 292-299.

Doran, J. W. and Parkin, T. B. 1994. Defining and assessing soil quality. *Defining Soil Qual. Sustain. Environ*. 35: 1-21.

Doran, J. W. and Parkin, T. B. 1997. Quantitative indicators of soil quality: a minimum data set. *Methods Assess. Soil Qual.* 49: 25-37

Elhottova, D., Kristufek, V., Triska, J., Chrastny, V., Uhlirova, E., Kalcik, J., and Picek, T. 2002. Immediate impact of the flood (Bohemia, August 2002) on selected soil characteristics. *Water Air Soil Pollut.* 173(1-4): 177–193.

Emmel, R.H., Solera, J.J., and Stux, R.L. 1977. *Atomic Absorption Methods Manual*. Instrumentation Laboratory Inc., Wilmington, pp.67-190.

Fowler, H.J., Cooley, D., Sain, S.R., and Thurston, M. 2010. Detecting change in UK extreme precipitation using results from the climateprediction.net BBC climate change experiment. *Extremes*, *13*(2): 241-267.

Furtak, K., Grządziel, J., Gałązka, A., and Niedzwiecki, J. 2020. Prevalence of unclassified bacteria in the soil bacterial community from floodplain meadows (fluvisols) under simulated flood conditions revealed by a metataxonomic approachss. *Catena, 188*: 104448.

Gangadharappa, K.R., Natarajan, A., Nair, K.M., Anil Kumar, K.S., Ramesh. M., Siddaramappa, R., snd Sudhir, K. 2008. Soil organic carbon stocks- a land quality indicator of degraded agro-ecosystems, 5th international symposium of interactions of soil minerals with organic components a n d microorganisms-ISMOM 2008 special issue of *J. Soil Sci. Plant Nutr.* 8(3): 103-104.

Gelaw, A.M., Singh, B.R., and Lal, R. 2015. Soil quality indices for evaluating smallholder agricultural land uses in northern Ethiopia. *Sustainability*, *7*(3): 2322-2337.

Gu, Y., Wang, P., and Kong, C.H. 2009. Urease, invertase, dehydrogenase and polyphenoloxidase activities in paddy soil influenced by allelopathic rice variety. *Eur. J. Soil Biol. 45*(5-6): 436-441.

Hansen, B., Alroe, H. F., and Kristensen, E. S. 2001. Approaches to assess the environmental impact of organic farming with particular regard to Denmark. *Agric. Ecosyst. Environ.* 83(1-2): 11–26.

Herrick, J. E. 2000. Soil quality: An indicator of sustainable land management? *Appl. Soil Ecol*. 15(1): 75–83.

Hesse, P. R. 1971. *A Textbook of Soil Chemical Analysis.* John Murray Publishers Ltd., London, 520p.

Hornick, S. B. 1992. Factors affecting nutritional quality of crops. *Am. J. Altern. Agric.* 7: 63-68.

Indira, B.V.N. and Covilakom, M.T.K. 2013. Characterization of Acidity in Acid Sulphate Soils of Kerala. *J. Life Sci.* 7(8): 907-912.

Jackson, M. L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Ltd., New Delhi, pp. 219-221.

Jegadeeswari, D., Muthumanickam, D., Chitdeshwari, T., and Shukla, A.K. 2017. Fertility Mapping of Available Micronutrients Status in the Soils of Dharmapuri District, Tamil Nadu, Using GIS and GPS Technique. *Madras Agric. J*. 104 (10-12): 330-334.

Johnson, D. L., Ambrose, S. H., Bassett, T. J., Bowen, M. L., Crummey, D.E., Isaacson, J. S., Johnson, D. N., Lamb, P., Saul, M. and Winter-Nelson, A. E. 1997. Meaning of environmental terms. *J. Environ. Qual.* 26(3): 581-589.

Joseph, C. 2014. Quality assessment of pokkali soils under different land uses. MSc thesis, Kerala Agricultural University, Thrissur, 101p.

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

Karlen, D. L., Ditzler, C. A., Andrews, A. S. 2003. Soil quality: why and how? *Geoderma*, 114(3-4): 145–156.

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(1): 4-10.

Karlen, D. L., Rosek, M. J., Gardner, J. C., Allan, D. L., Alms, M. J., Bezdicek, D. F., Flock, M. D., Huggins, R., Miller, B. S. and Staben, M. L. 1999. Conservation reserve program effects on soil quality indicators. *J. Soil Water Conserv*. 54(1): 439– 444.

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

KAU [Kerala Agricultural University]. 2016. Package of Practices Recommendations: Crops (15th Ed.). Kerala Agricultural University, Thrissur, 360p.

Kavitha. C. 2017. GIS based soil fertility mapping in agro ecosystems of Thrissur district, Kerala. PhD thesis, Cochin University of Science and Technology, Kochi, 107p.

Kay, B. D. and Grand, C. D.1996. Structural aspects of soil quality. In: MacEwan, J. M. and Crater, M. R. (eds), *Advances in Soil Quality for Land Management: Science, Practice and Policies.* Proceedings of an international symposium, University of Ballarat, Victoria, p. 37.

Kerala State Biodiversity Board 2018. *Impact of Flood/Landslides on Biodiversity*. Kerala State Biodiversity Board, Thiruvananthapuram, 250p.

Khalid, R.A., Patrick, W.H., and DeLaune, R.D. 1977. Phosphorus sorption characteristics of flooded soils. *Soil Sci. Soc. Am. J.* 41: 305-310.

Kozlowski, T. T. 1984. Extent, causes and impact of flooding. In: Kozlowski, T. T. (ed.), *Flooding and Plant growth*. Academic press, Harcout Brace Jovanovich Publishers, pp.1-5.

KSPB (Kerala State Planning Board) 2013. *Soil Fertility Assessement and Information Management for Enhancing Crop Productivity in Kerala*. Kerala State Planning Board, Thiruvananthapuram, pp. 447-457.

Kundu, S., Coumar, M. V., Saha, J. K., Rajendiran, S., Hati, K. M., Biswas, A. K., Reddy, K. S., and Rao, A.S. 2012. Assessing soil health of Vertisol of AESR 10.1 using selected physical, chemical and biological attributes of soils. *J. Indian Soc. Soil Sci.* 60(4): 281-287.

Lal, R. 2015. Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5): 5875-5895.

Larsen, W. E. and Pierce, F. J. 1991. Conservation and enhancement of soil quality. In: Lai, R. and Pierce, F.J. (eds), *Evaluation for Sustainable Land Management in the Developing World*. Proceedings of the international workshop on evaluation for sustainable land management in the developing world, Chiang Rai, Thailand. International Board for Soil Research and Management, Bangkok, Thailand, pp. 38-46.

Larsen, W. E. and Pierce, F. J. 1994. The dynamics of soil quality as a measure of sustainable management. In: Doran, J. W., Coleman, D. C., Bezdicek, D. F., and Stewart, B. A. (eds), *Defining Soil Quality for a Sustainable Environment*, Vol. 35, SSSA, pp. 37-51.

Li, H., Chen, X., Cai, X., He, L., and Huang, W. 2005. Assessment of soil quality using GIS & RS. In: Proceedings of the IEEE International Geoscience and Remote Sensing Symposium, July 2005, China,pp. 2972-2975.

Li, Y.Y., and Shao, M.A. 2006. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. *J. Arid Environ. 64*(1): 77-96.

Libohova, Z., Seybold, C., Wysocki, D., Wills, S., Schoeneberger, P., Williams, C., Lindbo, D., Stott, D., and Owens, P.R. 2018. Reevaluating the effects of soil organic matter and other properties on available water-holding capacity using the National Cooperative Soil Survey Characterization Database. *J. Soil Water Conserv.* 73(4): 411-421.

Lima, A. C. R., Brussaard, L., Totola, M. R., Hoogmoed, W. B., and de Goede, R. G. M. 2013. A functional evaluation of three indicator sets for assessing soil quality. *Appl. Soil. Ecol.* 64: 194-200.

Loeb, R.., Lamers, L.P., and Roelofs, J.G. 2008. Prediction of phosphorus mobilisation in inundated floodplain soils. *Environ. Pollut.* 156(2): 325-331.

Mace, O.G., Steinauer, K., Jousset, A., Eisenhauer, N., and Scheu, S. 2016. Flood-induced changes in soil microbial functions as modified by plant diversity. *PLoS One*, 11(11): e0166349.

Malla, R., Shrestha, S., Khadka, D., and Bam, C.R.2020. Soil Fertility Mapping and Assessment of the Spatial Distribution of Sarlahi District, Nepal. *Am. J. Agric. Sci.* 7(1): 8-16.

Mandal, D. and Jayaprakash, J. 2012. Land use effect on soil quality in humid subtropical region of India. *J. Indian. Soc. Soil Sci.* 60(4): 269-275.

Mandal, D. K., Mandal, C., and Velayutham, M. 2001. Development of a land quality index for sorghum in Indian semi-arid tropics (SAT). *Agric. Syst.* 70(1): 335-350.

Massoumi, A. and Cornfield, A. H. 1963. A rapid method for determining sulphate in water extracts of soils. *Analyst*, 88(1045): 321-322.

Mc Bratney, A. B., Santos, M.M., and Minasny, B. 2003. On digital soil mapping. Geoderma, 117(1-2): 3-52.

Mentzer, J.L., Goodman, R.M., and Balser, T.C. 2006. Microbial response over time to hydrologic and fertilization treatments in a simulated wet prairie. *Plant Soil,* 284(1-2): 85–100.

Mishra, G., Marzaioli, R., Giri, K., Borah, R., Dutta, A., and Jayaraj, R.S.C. 2017. Soil quality assessment under shifting cultivation and forests in Northeastern Himalaya of India. *Arch. Agron. Soil Sci.* 63(10): 1355-1368.

Mohapatra, P. K. and Singh, R. D. 2003. Flood management in India. *Nat. Hazards* 28: 131-143.

Mukherjee, A. and Lal, R. 2014. Comparison of soil quality index using three methods. *PLoS One* 9(8): 105-981.

Natarajan, A., Janakiraman, M., Manoharan, S., Kumar, K. S. A., Vadivelu, S., and Sarkar, D. 2005. *Land Degradation and Desertification: Assessment, Mitigation and Remediation.* Springer Dordrecht Heidelberg London, New York. 234p.

Neatrour, M.A., Webster, J.R., and Benfield, E.F. 2004. The role of floods in particulate organic matter dynamics of a southern Appalachian river-floodplain ecosystem. *J. North Am. Benthological Soc*. 23(2): 198–213.

Nehrani, S.H., Askari, M.S., Saadat, S., Delavar, M.A., Taheri, M., and Holden, N.M. 2020. Quantification of soil quality under semi-arid agriculture in the northwest of Iran. *Ecological Indicators*, *108*: 105770.

Nimmo, J.R. 2004. Porosity and pore size distribution. *Encyclopedia Soils Environ. 3*(1): 295-303.

Njoku, C. and Okoro, G, C. 2015. Effect of flooding on soil properties an AbakalikiSouthi- Eastern Nigeria. Scholarly. *J. Agric. Sci*. 5(5): 165-168.

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

Nosrati, K. 2013. Assessing soil quality indicator under different land use and soil erosion using multivariate statistical techniques. *Environ. Monitoring Assess.* 185(4): 2895-2907.

Olorunfemi, I.E., Fasinmirin, J.T., and Ojo, A.S. 2016. Modeling cation exchange capacity and soil water holding capacity from basic soil properties. *Eurasian J. Soil Sci.* 5(4): 266- 274.

Ou, Y., Rousseau, A.N., Wang, L., Yan, B., Gumiere, T., and Zhu, H. 2019. Identification of the alteration of riparian wetland on soil properties, enzyme activities and microbial communities following extreme flooding. *Geoderma*, *337*: 825-833.

Palm, C., Sanchez, P., Ahamed, S., and Awiti, A. 2007. Soils: a contemporary perspective. *Annu. Rev. Environ. Resour.* 32: 99 -129.

Panse, V.G. and Sukhatme, P.V. 1978. *Statistical Methods for Agricultural Workers.* ICAR, New Delhi, pp: 68-75.

Papendick, R. I., Hornick, S. B., and Parr, J. F.1991. Soil quality: The foundation of a sustainable agriculture. *Proc. Int. Conf. Kyusei Nat. Farming* 2: 7-11.

Parker, F. W., Nelson, W. L., Winter, E., and Miles, I. E. 1951. The broad interpretation of soil test informations. *Agron. J.* 43(3): 105-112.

Parr, J. F., Papendick, R. I., Hornick, S. B., and Meyer, R. E. 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture. *Am. J. Altern. Agric.* 7: 5-11.

Patil, P.L., Bansode, C., Pawadashetti, D., Ramachandraiah. H.C., Devaranavadagi, V.S., Naik, A., Hundekar, S.T., and Dasog, G.S. 2018. Identification of soil fertility constraints by GIS in Northern Dry Zone of Karnataka for site specific recommendations. *J. Farm Sci*., 31(1): 54-63.

Patil, P. L., Bidari, B. I., Hebbara, M., Katti, J., Dilvaranaik, S., Vishwanatha, S., GeetanjalI, H. M., and Dasog, G. S. 2017. Identification of soil fertility constraints by GIS in Bedwatti sub watershed under Northern dry zone of Karnataka for site specific recommendations. *J. Farm Sci.* 30(2): 206-211.

Polyakov, V.O. and Nearing, M.A. 2003. Sediment transport in rill flow under deposition and detachment conditions. *Catena, 51*(1): 33-43.

Ponnamperuma, F. N. 1984. Effects of flooding on soils. In:Kozlowski, T. T. (ed.), *Flooding and Plant growth*. Academic press, Harcout Brace Jovanovich Publishers, pp. 9-45.

Powers, R. F., Tiarks, A. E., and Boyle, J. R. 1998. Assessing soil quality: practicable standards for sustainable forest productivity in the United States. In: Davidson, E.A., Adams, M.B., and Ramakrishna, K. (eds), *The Contribution of Soil Science to the Development and Implementation of Criteria and*

Indicators of Sustainable Forest Management. SSSA Special Publication No. 53, SSSA, Madison, WI, pp. 53-80.

Prabhavati, K., Dasog, G. S., Patil, P. S., 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.

Pulido, M., Schnabel, S., Contador, J.F.L., Lozano-Parra, J., and Gómez-Gutierrez, A. 2017. Selecting indicators for assessing soil quality and degradation in rangelands of Extremadura (SW Spain). *Ecological indicators*, *74*: 49-61.

Rabot, E., Wiesmeier, M., Schlüter, S., and Vogel, H. J. 2018. Soil structure as an indicator of soil functions: A review. *Geoderma,* 314: 122–137.

Rajan, K., Natarajan, A., Anil Kumar, K.S., Badrinath, M.S., and Gowda, R.C. 2010. Soil organic carbon-the most reliable indicator for monitoring land degradation by soil erosion. *Curr. Sci.* 99(6): 823-827.

Rajashekaran, P., Nair, K. M., John, K. S., Kumar, P. S., Kutty, M. N., and Nair, A. R. 2014. Soil fertility related constraints to crop production in Kerala. *Indian J. Fertil.* 10(11): 56-62.

Rakesh, S., and Kunal, S. 2019. Soil fertility appraisal for apple orchards of Himachal Pradesh using GPS and GIS techniques. *Indian J. Hortic*. 76(3): 417-422

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

Ramamurthy, V., Nalatwadmath, S. K., Srinivas, S., Rama Mohan Rao, M. S., Shivaprasad. C. R., Adhikari, R. N., Naidu, L. G. K., Patil, S. L., Raizada, A., Dipak Sarkar, Singh, S. K., and Mishra, P. K. 2009. *Soil Erosion in Karnataka.* National Bureau of Soil Survey and Land Use Planning, Nagpur, 70p.

Ramos, J.C., Bertol, I., Bandeira, D.H., Barbosa, F.T., and Zangiski, F. 2019. Path coefficient analysis, a different approach to identify soil quality indicators. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *23*(7): 545-551.

Ravikumar, P. and Somashekar, R. K. 2005. Evaluation of nutrient index using organic carbon, available P and available K concentrations as a measure of soil fertility in Varahi River basin, India. In: Proceedings of the International Academy of Ecology and Environmental Sciences, December 2013, India, pp. 330-343.

Rawal, N., Acharya, K.K., Bam, C.R., and Acharya, K. 2018. Soil Fertility Mapping of Different VDCs of Sunsari District, Nepal Using GIS *Int. J. Appl. Sci. Biotechnol.* 6(2): 142-151.

Reis, D.A., Lima, C.L.R.D., and Bamberg, A.L. 2019. Developing a Soil Physical Quality Index (SPQi) for lowlands under different deployment times of no-tillage. *Scientia Agricola*, *76*(2): 157-164.

Rezaei, S. A., Gilkes, R. J., and Andrews, S. S. 2006. A minimum data set for assessing soil quality in rangelands. *Geoderma*, 136(1-2): 229-234.

Robinson, G. W. 1922. A new method for the mechanical analysis of soils and other dispersions. *J. Agric. Sci*. 12: 306-321.

Roming, D. E., Garlynd, M. J., Harris, R. F and Mc Sweeney, K. 1995. How farmers assess soil health and quality. *J. Soil Water Conserv.* 50(3): 229-226.

Rossi, J.P., Franc, A., and Rousseau, G.X. 2009. Indicating soil quality and the GISQ. *Soil Biol. Biochem.* 41(2): 444-445.

Ruehlmann, J., Korschens, M., and Graefe, J. 2006. A new approach to calculate the particle density of soils considering properties of the soil organic matter and the mineral matrix. *Geoderma*, *130*(3-4): 272-283.

Sakin, E. 2012. Organic carbon organic matter and bulk density relationships in arid-semi arid soils in Southeast Anatolia region. *Afr. J. Biotechnol.* 11(6): 1373-1377.

Salma, D., Munaswamy, V., Krishna, T.G., Sumathi, V., and Reddy, B.R. 2019. GPS and GIS based Soil Fertility Maps and Identification of Soil Related Constraints for Chickpea Growing Soils of Owk Mandal, Kurnool District (A.P). *Int. J. Curr. Microbiol .App. Sci.* 8(6): 1241-1247.

Sarma, V. A. K., Krishnan, P., and Budhihal, S. L., 1987. *Laboratory methods.* NBSS Pub. 14, Technical Bulletin, National Bureau of Soil Survey and Land Use Planning, Nagpur, p. 49

Sarvi, V. and Matnifar, H.R. 2019. Survey Fertility Mapping of the Maghan Area Using Global Information System (GIS) and Analytic Hierarchy Process (AHP). ***Spring,*** 23(1): 379-389.

Schoenholtz, S. H., VanMiegroet, H., and Burger, J. A. 2000. A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *For. Ecol. Manag.* 138(1-3): 335-356.

Singer, M. J. and Ewing, S. 2000. Soil quality. In: Sumner (ed), *Handbook of Soil Science*. CRC press, Boca Raton, F. L, pp. 271-298.

Singh, A. K., Mazumdar, A. R., Saha, A. R., and Kundu, D. K. 2017. Soil quality changes resulting from long-term fertilizer application under intensive cropping system in alluvial soils. *Commun. Soil Sci. Plant Anal.* 48(13): 1503-1510.

Shalima Devi, G. M. and Anil Kumar, K. S. 2009. Characteristics of coffee growing soils and their organic carbon stocks in Karnataka state. *Agropedology,* 19(1): 6-14.

Sharma, K.L., Grace, J.K., Mishra, P.K., Venkateswarlu, B., Nagdeve, M.B., Gabhane, V.V., Sankar, G.M., Korwar, G.R., Chary, G.R., Rao, C.S., and Gajbhiye, P.N. 2011. Effect of soil and nutrient-management treatments on soil quality indices under cotton-based production system in rain fed semi-arid tropical vertisol. *Soil Sci. Plant Anal.* 42(11): 1298-1315.

Sharma, K.L., Grace, J.K., Raj, M., Mittal, S.B., Singh, J., Sharma, S.K., Sangwan, P.S., Sidhpuria, M.S., Vittal, K.P.R., Mishra, P.K., and Sankar, G.M. 2013.

Improvement and assessment of soil quality under long-term conservation agricultural practices in hot, arid tropical aridisol. *Commun. Soil Sci. Plant Anal.* 44(6): 1033-1055.

Sharma, K. L. and Mandal, B. 2009. Soil quality and its relevance in sustainable agriculture. *J. Ind. Soc. Soil Sci.* 57 (4): 572-586.

Shukla, M. K., Lal, R., and Ebinger, M. 2006. Determining soil quality indicators by factor analysis. *Soil Tillage Res.* 87(2): 194-204.

Sims, J.T. and Johnson, G.V. 1991. Micronutrient soil tests in agriculture. In: Mortvedt, J.J., Cose, F.R., Shuman, L.M., and Welch, R.M. (eds.), Method of Soil Analysis. Soil Science Society of America, Madison, USA, pp. 427-472.

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

Sulieman, M., Saeed, I., Hassaballa, A., and Rodrigo-Comino, J. 2018. Modeling cation exchange capacity in multi geochronological-derived alluvium soils: An approach based on soil depth intervals. *Catena*, *167*: 327-339.

Tabatabai, M. A. and Bremner, J. M. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil biol. biochem.* 1(4): 301-307.

Taylor, J. P., Wilson, M., Mills, S. and Burns, R. G. 2002. Comparison of microbial numbers and enzymatic activities in surface soils and subsoils using various techniques. *Soil Biol. Biochem*. 34(3): 387–401.

Thakor, K. M., Dharaiya, N., Singh, V., Patel, A., Mehmood, K., and Kalubarme, M. H. 2014. Spatial variability mapping of micronutrients to improve productivity using geoinformatics technology in Gujarat state, India. *Int. J. Sci. Engg. Res.* 5(7): 1021- 1027.

Unger, I. M., Motavalli, P. P., and Muzika, R. M. 2009a. Changes in soil chemical properties with flooding: a field laboratory approach. *Agric. Ecosyst. Environ*. 131(1-2): 105-110.

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

Utobo, E. B. and Tewari, L. 2014. Soil enzymes as bioindicators of soil ecosystem status. *Appl. Ecol. Environ Res.* 13(1): 147-169.

USDA [United States Department of Agriculture]. 2006. Soil bulk density/moisture/aeration [on line]. Soil Quality Kit – Guides for Educators, Natural Resources Conservation Services, USDA.Available: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053260.pdf [17 July 2020].

Vadyunina, A. F. and Korchagina, Z. A. 1986. Methods of studying the physical properties of soils. *Moscow: Agropromizdat*, 416p.

Vasu, D., Singh, S. K., Ray, S. K., Duraisami, V. P., Tiwary, P., Chandran, P., Nimkar, A. M., and Anantwar, S. G. 2016. Soil quality index (SQI) as a tool to evaluate crop productivity in semi-arid Deccan plateau, India. *Geoderma*, 282: 70-79.

Vepraskas, M.J. and Faulkner, S.P. 2001. Redox chemistry of hydric soils. In: Richardson, J.L., Vepraskas, M.J. (Eds.), *Wetland Soils*: *Genesis, Hydrology, Landscapes and Classification*. Lewis Publishers, Florida, pp. 175-422.

Walkley, A. J. and Black, I. A. 1934. Estimation of soil organic carbon by chromic acid titration method. *Soil Sci.* 31: 29-38.

Wang, Q., Liu, J., Wang, Y., Guan, Y., Liu, Q., and Dui-an Lv. 2012. Land use effects on soil quality along a native wetland to cropland chronosequence. *Eur. J. Soil Biol.* 53: 114-120.

Wander, M. M. and Bollero, G. A. 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Sci. Soc. Am. J.* 63(4): 961-971.

Warkentin, B. P. 1995. The changing concept of soil quality. *J. Soil Water Conserv.* 50(3): 226-228.

Yang, J., Liu, J., Hu, X., Li, X., Wang, Y., and Li, H. 2013. Changes of soil organic carbon, nitrogen and phosphorus concentrations under different land uses in marshes of Sanjiang Plain. *Acta Ecologica Sinica*, *33*(6): 332-337.

Zhang, Y., Lin, X., and Werner, W. 2003. The effect of soil flooding on the transformation of Fe oxides and the adsorption/desorption behavior of phosphate. *J. Plant Nutr. Soil Sci. 166*(1): 68-75.

Zhanfeng, L.I.U., Bojie, F.U., Guohua, L.I.U., and Yongguan, Z.H.U. 2006. Soil quality: concept, indicators and its assessment. *Acta Ecologica Sinica*, 26(3): 901-913.

Zornoza, R., Acosta, J.A., Bastida, F., Domínguez, S.G., Toledo, D.M., and Faz, A. 2015. Identification of sensitive indicators to assess the interrelationship between soil quality, management practices and human health. *Soil*, 1(1): 173-185.

SOIL QUALITY ASSESSMENT AND GENERATION OF GIS MAPS IN FLOOD AFFECTED MANANTHAVADY BLOCK OF WAYANAD DISTRICT

By

FOUSIYA P.V.

(2018-11-072)

ABSTRACT

Submitted in partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY

COLLEGE OF AGRICULTURE, PADANNAKKAD

KASARAGOD – 671314

KERALA, INDIA

2020

Abstract

ABSTRACT

A study entitled “Soil quality assessment and generation of GIS maps in flood affected Mananthavady block of Wayanad district” was conducted during 2018-20 with the objectives to assess the soil quality of post-flood soils of Mananthavady block in Wayanad district, to work out the soil quality index (SQI) and to develop maps on soil characters using GIS techniques.

A preliminary survey was conducted to identify the flood affected areas and to understand the cropping history and nutrient management practices of the locality. It was found that, the entire area consisting of five panchayaths namely Vellamunda, Thirunelly, Thondernadu, Edavaka and Thavinhal and Mananthavady municipality were affected by flood. Banana, paddy, coffee, pepper, vegetables, arecanut, coconut, rubber and tea are the major crops grown in the area. Majority (96%) of the farmers belonged to the small and marginal category with farm size less than 2ha.

Geo-referenced surface soil samples were collected from a depth of 0-20cm from hundred flood affected locations of Mananthavady block for analysing physical, chemical and biological properties. Principal Component Analysis (PCA) was used for the selection of Minimum Data Set (MDS) for the assessment of Soil quality. The selected parameters were ECEC, pH, organic carbon, percent silt, Available Fe, K, B, S, P, and Zn. Soil Quality Index (SQI) was computed for each sampling location by assigning scores and weight to each MDS parameter. Thematic maps of various soil attributes, soil quality, land quality and nutrient indices were generated in ArcGIS 10.3 software.

The investigation revealed that, the majority of the area had a bulk density between 1.4 and 1.6 Mg m^{-3}(61%), particle density between 2.2 to 2.4 Mg m^{-3} (50%), porosity between 30 and 50 percentage (85%) and 70 % of the samples recorded maximum water holding capacity between 30 and 50 percentage . The predominant soil textural class in the study area was sandy clay loam (60%) followed by clay loam (17%) and sandy loam (14%).

Chemical analysis showed that, the study area was dominated by very strongly acid soils (47%) followed by strongly acidic (25%) soils and 51% of soils had

exchangeable acidity between 2 and 4 cmol (p^+) Kg^{-1}. Electrical conductivity was less than 1 dSm^{-1} in all over the study area. Organic carbon content was medium in 61 % of the soils and available nitrogen was low in 94 % of the samples. The available P (64%) and available K (41%) were observed to be medium in the study area. Available calcium and magnesium were found to be adequate in 87% and 93% per cent of soil samples respectively. Majority of the soils were deficient in available S (85%) and were sufficient in available Cu (73%). The entire study area was sufficient in available Fe, Mn, Zn and was deficient in available B. Most of the study area had a low status of exchangeable Na (96%), exchangeable Al recorded values between 2 and 4 cmol (p^+) Kg^{-1}(49%) and ECEC between 5 and 16 cmol (p^+) Kg^{-1} (94%).

The soil quality was worked out by SQI and it was found to be good in 24% of the study locations, whereas 73% of the samples recorded soil quality at medium level. Highest mean value of soil quality was observed from Thondernadu followed by Vellamunda and lowest value was reported from Thirunelly. Nutrient index of organic carbon was high in Thondernadu and medium in other panchayaths. Whereas Nutrient index of nitrogen was low in entire study area. Nutrient index for phosphorous was medium in Thondernadu, and Vellamunda and was high in all other panchayaths. Nutrient index for potassium was low in Thirunelly and Edavaka and was medium in rest of the areas. Land Quality Index of 69% of study area were found to be very low.

Comparison of post flood with pre flood data of KSPB (2013) showed that, there was a decrease in extremely acid and moderately acid soil test values. The post flood data also revealed that there was an increase in available P, Ca, Mg, Zn, and Cu whereas there was a decrease in organic carbon content and availability of potassium, sulphur, and boron. Thus the variations in the status of pH, organic carbon and nutrients compared to pre flood study necessitate a revision in soil management practices.

Appendices

Appendix I

Performa of survey questionnaire

1. Name of the panchayath :

2. Name of the farmer :

3. Address :

4. Size of holding :

5. Survey no. :

6. Geo coordinates of the sample :

7. Crops cultivated :

8. Nutrient management practices :

9. Depth of deposition :

Appendix II

Area and crop management of sampled locations

Panchayath/ Muncipality	Sample No.	Size of holding	Major Crops	Nutrient management
Mananthavady	1	30 cent	Paddy	Conventional
	2	20 cent	Paddy	Conventional
	3	85 cent	Coconut + Cocoa	INM
	4	30 cent	Arecanut + Banana	Organic
	5	1 ha	Coconut	INM
	6	25 cent	Cassava	Organic
	7	90 cent	Coconut + Nutmeg	Conventional
	8	1.5 ha	Rubber + Coffee + Pepper + Jack	INM
	9.	1.25ha	Rubber	INM
	10	40cent	Coffee	Conventional
	11	50 ha	Banana + Coffee	INM
	12	10cent	Coffee	Organic
	13	43 cent	Coffee + Pepper	INM
	14	1.6 ha	Banana + Coffee	Conventional
	15	10 cent	Arecanut + Pepper	INM
	16	20 cent	Cassava	Organic
	17	60cent	Paddy	Conventional
	18	20 cent	Arecanut+ Fodder grasss	INM
	19	15 cent	Cowpea	Organic
Edavaka	20	50 cent	Coffee	Conventional
	21	45 cent	Coffee	INM
	22	70 cent	Banana + Arecanut	Conventional
	23	15 cent	Coffee+ Cassava	Conventional
	24	2.5ha	Rubber + Turmeric	INM
	25	1 ha	Rubber	INM
	26	35 cent	Coffee + Arecanut	Organic
	27	1 ha	Paddy	Conventional
	28	1.5 ha	Coconut + Coffee	Conventional
	29	25 cent	Coffee	Organic
	30	30 cent	Coffee	INM
	31	10 cent	Cowpea	Organic
	32	50 cent	Paddy	INM
	33	90 cent	Banana + Pepper	Conventional
	34	50 cent	Banana	Conventional
	35	54 cent	Coffee + Fodder grass	Organic

Panchayath/ Muncipality	Sample No.	Size of holding	Major Crops	Nutrient management
	36	1.34 ha	Arecanut + Pepper + Coffee	Conventional
Thirunelly	37	35 cent	Paddy	Organic
	38	20 cent	Banana	INM
	39	15 cent	Coconut + Arecanut + Fodder grass	INM
	40	50 cent	Cowpea	Organic
	41	36 cent	Coconut + Ginger	Organic
	42	20 cent	Coconut	INM
	43	25 cent	Paddy	Organic
	44	45 cent	Paddy	Organic
	45	30 cent	Coconut + Arecanut+ Pepper	Conventional
Thavinhal	46	I ha	Banana	Conventional
	47	2 ha	Banana + Arecanut	Conventional
	48	50 cent	Cassava	Organic
	49	2.5 ha	Banana + Coffee	Conventional
	50	30 cent	Coffee	INM
	51	15 cent	Coffee	Conventional
	52	90 cent	Banana + Coffee	Conventional
	53	50 cent	Banana	INM
	54	1 ha	Arecanut+ Coffee	Conventional
	55	2.1 ha	Banana + Arecanut	Conventional
	56	50 cent	Coffee	Conventional
	57	25 cent	Banana + Arecanut	INM
	58	60 cent	Coffee + Banana	Conventional
	59	45 cent	Banana	Conventional
	60	14 cent	Coffee	Organic
	61	35 cent	Banana + Cassava	INM
	62	20 cent	Paddy	Organic
	63	10 cent	Coffee	Conventional
	64	45 cent	Banana	Conventional
	65	20 cent	Coffee + Pepper	Organic
Thondernadu	66	45 cent	Coffee	Conventional
	67	24 cent	Cassava + Coffee	Organic
	68	2 ha	Rubber	Conventional
	69	50 cent	Coffee + Banana + Fodder grass	INM
	70	30 cent	Coffee + Fodder grass	INM

Panchayath/ Muncipality	Sample No.	Size of holding	Major Crops	Nutrient management
	71	25 cent	Banana+ Nutmeg	Conventional
	72	15 cent	Paddy	Organic
	73	35 cent	Banana + Cassava	Conventional
	74	10 cent	Coconut + Fodder grass	INM
	75	20 cent	Coconut + Cassava	INM
	76	55 cent	Coffee	Conventional
	77	15 cent	Coffee + Cassava	INM
	78	1 ha	Banana + Cassava	Conventional
	79	1.5 ha	Coconut	Conventional
	80	2.2 ha	Coconut	Conventional
	81	15 cent	Banana + Coffee	INM
	82	30 cent	Coconut + Fodder grass	INM
Vellamunda	83	50 cent	Arecanut + Pepper	INM
	84	70 cent	Paddy	Conventional
	85	1 ha	Rubber	Conventional
	86	35 cent	Coffee + Pepper	INM
	87	20 cent	Coffee	INM
	88	1 .5 ha	Paddy	Conventional
	89	30 cent	Coffee + Pepper	INM
	90	15 cent	Coffee	Organic
	91	75 cent	Coffee + Banana	Conventional
	92	25 cent	Coffee + Banana + Jack	Organic
	93	50 cent	Paddy	Conventional
	94	1 ha	Coconut	Conventional
	95	35 cent	Arecanut	Conventional
	96	15 cent	Pepper + Jack	Organic
	97	10 cent	Coffee + Cocoa	INM
	98	80 cent	Arecanut + Pepper	INM
	99	2.3 ha	Coconut + Fodder grass	INM
	100	15 cent	Coffee + Cocoa	Conventional

Appendix III

ANALYSIS RESULTS (for individual samples)

A. Results of physical parameters (for individual samples)

Sample No.	Bulk Density at 15 cm (Mg m^{-3})	Bulk Density at 30 cm (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	MWHC (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
Mananthavady Municipality									
1	1.60	1.61	2.19	26.66	35.81	59.20	16.20	24.60	Sandy clay loam
2	1.34	1.29	2.42	44.81	34.59	57.40	12.40	30.20	Sandy clay loam
3	1.47	1.47	2.48	40.93	40.19	68.30	13.90	17.80	sandy loam
4	1.18	1.18	2.57	54.09	34.49	65.70	16.00	18.30	sandy loam
5	1.53	1.41	2.51	39.02	33.87	52.20	17.00	30.80	Sandy clay loam
6	1.49	1.42	2.42	38.57	40.81	54.20	12.10	33.70	Sandy clay loam
7	1.31	1.30	2.36	44.39	35.63	70.20	13.90	15.90	Sandy loam
8	1.33	1.35	2.42	44.93	40.32	77.30	11.90	10.80	Sandy loam
9	1.18	1.41	2.40	50.98	41.02	55.20	15.80	29.00	Sandy clay loam
10	1.21	1.16	2.27	46.60	54.10	52.20	15.00	32.80	Sandy clay loam
11	1.42	1.34	2.42	41.28	49.38	63.20	10.00	26.80	Sandy clay loam
12	1.12	1.23	2.40	53.20	57.66	53.20	10.00	36.80	Sandy clay
13	1.27	1.15	2.34	45.84	54.25	50.70	11.50	37.80	Sandy clay
14	1.17	1.16	2.38	51.09	62.65	56.80	10.00	33.20	Sandy clay loam
15	1.38	1.38	2.34	41.23	46.84	58.20	14.00	27.80	Sandy clay loam
16	1.38	1.34	2.45	43.77	43.08	63.70	13.50	22.80	Sandy clay loam
17	1.53	1.37	2.63	41.94	34.77	61.20	15.00	23.80	Sandy clay loam
18	1.21	1.22	2.54	52.45	35.43	70.70	11.80	17.50	Sandy loam
19	1.29	1.31	2.34	44.65	43.77	57.30	17.10	25.60	Sandy clay loam
Edavaka Panchayth									
20	1.52	1.54	2.48	38.48	36.70	71.90	11.70	16.40	Sandy loam
21	1.22	1.33	2.48	50.65	36.52	69.40	9.30	21.30	Sandy clay loam

Sample. No.	Bulk Density at 15 cm (Mg m^{-3})	Bulk Density at 30 cm (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	MWHC (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
22	1.24	1.50	2.48	49.88	46.16	68.60	10.00	21.40	Sandy clay loam
23	1.20	1.19	2.45	51.24	36.72	70.90	10.90	18.20	Sandy loam
24	1.23	1.28	2.29	46.33	49.59	66.80	8.70	24.50	Sandy clay loam
25	1.28	1.18	2.48	48.54	47.15	63.40	13.80	22.80	Sandy clay loam
26	1.33	1.26	2.40	44.51	40.74	55.20	17.20	27.60	Sandy clay loam
27	1.14	1.26	2.47	53.79	43.36	65.00	24.20	10.80	Sandy loam
28	1.22	1.18	2.30	47.06	46.32	68.50	22.60	8.90	Sandy loam
29	1.37	1.40	2.10	34.47	41.16	64.20	22.10	13.70	Sandy loam
30	1.32	1.38	2.44	46.06	32.57	80.50	14.00	5.50	Loamy sand
31	1.27	1.26	2.46	48.19	44.33	65.80	23.50	10.70	Sandy loam
32	1.22	1.26	2.54	51.80	41.92	58.40	21.10	20.50	Sandy clay loam
33	1.26	1.22	2.34	46.24	52.12	58.40	15.10	26.50	sandy clay loam
34	1.07	1.00	2.34	54.18	60.83	60.80	14.20	25.00	Sandy clay loam
35	1.07	1.16	2.24	52.42	58.04	57.60	12.70	29.70	Sandy clay loam
36	1.18	1.23	2.33	49.63	58.68	42.20	28.20	29.60	Clay loam
Thirunelly Panchayath									
37	1.30	1.32	2.48	47.57	40.17	40.20	29.30	30.50	Clay loamy
38	1.22	1.20	2.36	48.53	53.69	52.30	18.20	29.50	Sandy clay loam
39	1.50	1.45	2.36	36.33	41.72	52.80	18.60	28.60	Sandy clay loam
40	1.50	1.42	2.36	36.17	41.98	55.80	25.70	18.50	Sandy clay loam
41	1.60	1.57	2.32	31.03	59.63	15.80	15.70	68.50	Clay soil
42	1.27	1.42	2.43	47.66	39.36	66.50	14.60	18.90	Sandy loam
43	1.25	1.24	2.28	45.13	58.31	16.80	17.30	65.90	Clay soil
44	1.54	1.47	2.43	36.80	37.23	69.60	14.60	15.80	Sandy loam
45	1.50	1.40	2.29	34.31	41.29	55.80	16.40	27.80	Sandy clay loam
Thavinhal Panchayath									
46	1.59	1.39	2.33	31.97	45.55	60.80	16.57	22.63	Sandy clay loam
47	1.53	1.53	2.38	35.71	46.79	54.90	16.30	28.80	Sandy clay loam
48	1.42	1.42	2.33	39.16	34.76	59.70	16.00	24.30	Sandy clay loam

Sample No.	Bulk Density at 15 cm (Mg m^{-3})	Bulk Density at 30 cm (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	MWHC (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
49	1.43	1.44	2.41	40.66	41.70	60.32	14.08	25.60	Sandy clay loam
50	1.34	1.33	2.39	43.93	47.84	50.30	17.20	32.50	Sandy clay loam
51	1.38	1.39	2.37	41.77	45.46	49.86	18.44	31.70	sandy clay loam
52	1.29	1.29	2.38	45.92	43.37	62.31	14.04	23.65	Sandy clay loam
53	1.10	1.06	2.32	52.73	49.52	37.60	27.80	34.60	Clay loam
54	1.16	1.15	2.38	51.26	43.75	56.20	15.44	28.36	Sandy clay loam
55	1.14	1.17	2.28	50.00	46.10	54.36	19.06	26.58	Sandy clay loam
56	1.12	1.05	2.24	49.90	42.51	53.90	21.45	24.65	Sandy clay loam
57	1.35	1.36	2.19	38.36	56.66	55.36	19.02	25.62	sandy clay loam
58	1.39	1.05	2.26	38.67	54.38	32.65	31.79	35.56	Clay loam
59	1.33	1.09	2.53	47.25	52.44	31.26	32.15	36.59	Clay loam
60	1.31	1.11	2.34	44.10	55.70	42.32	26.45	31.23	Clay loam
61	1.40	1.35	2.28	38.60	62.83	63.53	14.12	22.35	Sandy clay loam
62	1.42	1.11	2.16	34.06	49.99	65.32	17.32	17.36	Sandy loam
63	1.13	1.09	2.13	46.85	50.78	18.25	47.50	34.25	Silty clay loam
64	1.12	1.18	2.17	48.40	48.65	16.32	50.15	33.53	Silty clay loam
65	1.19	1.23	2.21	46.15	45.20	32.14	31.36	36.50	Clay loam
Thondernadu Panchayath									
66	1.14	1.17	2.28	50.00	46.10	54.36	19.06	26.58	Sandy clay loam
67	1.24	1.16	2.26	45.31	45.40	50.25	10.19	39.56	Sandy clay
68	1.29	1.26	2.15	39.95	45.82	52.69	11.06	36.25	Sandy clay
69	1.24	1.25	2.19	43.38	46.87	55.16	11.48	33.36	sandy clay loam
70	1.21	1.19	2.21	45.25	49.62	52.80	14.86	32.34	Sandy clay loam
71	1.37	1.39	2.20	37.64	57.75	38.40	26.10	35.50	Clay loam
72	1.29	1.25	2.25	42.67	52.37	36.24	29.48	34.28	Clay loam
73	1.34	1.34	2.26	40.71	54.11	55.20	13.30	31.50	Sandy clay loam
74	1.32	1.23	2.19	39.80	56.15	58.13	13.62	28.25	Sandy clay loam
75	1.21	1.14	2.54	52.36	63.04	55.96	13.48	30.56	Sandy clay loam
76	1.28	1.32	2.42	47.11	61.24	52.14	13.30	34.56	Sandy clay loam

Sample No.	Bulk Density at 15 cm (Mg m^{-3})	Bulk Density at 30 cm (Mg m^{-3})	Particle Density (Mg m^{-3})	Porosity (%)	MWHC (%)	Sand (%)	Silt (%)	Clay (%)	Textural class
77	1.22	1.25	2.27	46.07	63.70	50.13	17.22	32.65	sandy clay loam
78	1.39	1.39	2.43	42.74	50.75	58.63	16.05	25.32	Sandy clay loam
79	1.32	1.35	2.37	44.26	47.98	54.23	15.29	30.48	Sandy clay loam
80	1.28	1.17	2.39	46.49	43.22	52.36	13.12	34.52	Sandy clay loam
81	1.35	1.28	2.28	41.06	41.31	61.54	12.67	25.79	Sandy clay loam
82	1.37	1.26	2.41	43.11	42.08	62.30	13.14	24.56	Sandy clay loam
Vellamunda Panchayath									
83	1.32	1.24	2.33	40.21	50.58	41.50	24.30	34.20	Clay loam
84	1.36	1.70	2.32	41.56	42.41	40.25	24.50	35.25	Clay loam
85	1.37	1.46	2.35	41.70	40.09	59.66	14.69	25.65	Sandy clay loam
86	1.37	1.42	2.39	42.89	50.61	55.23	16.41	28.36	Sandy clay loam
87	1.45	1.54	2.48	41.53	64.10	62.13	11.52	26.35	Sandy clay loam
88	1.48	1.56	2.50	40.80	55.26	55.63	10.37	34.00	Sandy clay loam
89	1.62	1.49	2.44	33.64	44.92	56.23	11.62	32.15	Sandy clay loam
90	1.31	1.35	2.36	44.49	46.48	42.65	21.55	35.80	clay loam
91	1.29	1.11	2.24	42.57	47.08	37.80	24.64	37.56	Clay loam
92	1.32	1.10	2.21	40.22	49.80	40.79	22.65	36.56	Clay loam
93	1.39	1.29	2.38	41.60	56.00	39.56	22.98	37.46	Clay loam
94	1.48	1.39	2.42	38.84	42.56	52.65	17.55	29.80	Sandy clay loam
95	1.63	1.41	2.45	33.52	37.49	57.68	15.97	26.35	Sandy clay loam
96	1.42	1.44	2.44	41.80	44.24	60.58	13.79	25.63	Sandy clay loam
97	1.23	1.42	2.28	46.08	48.62	44.85	18.87	36.28	Clay loam
98	1.34	1.32	2.30	41.49	43.59	56.35	10.09	33.56	Sandy clay loam
99	1.38	1.39	2.49	44.58	46.52	52.32	15.53	32.15	Sandy clay loam
100	1.37	1.37	2.43	43.84	49.23	58.36	11.39	30.25	Sandy clay loam

B. Results of soil pH, Ex. Acidity, EC and available macro nutrients (for individual samples)

Sample No.	pH	Ex. Acidity (cmol p^+ Kg^{-1})	EC (dSm^{-1})	OC (%)	N (Kg ha^{-1})	P (Kg ha^{-1})	K (Kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	S (mg kg^{-1})
Mananthavady Municipality										
1	5.15	1.79	0.11	0.57	181.89	23.78	79.97	400.00	300.00	6.60
2	4.81	2.98	0.08	1.35	282.24	19.34	124.77	580.00	300.00	1.59
3	4.44	3.14	0.04	0.45	156.80	103.12	36.18	260.00	96.00	2.41
4	5.50	1.40	0.09	0.42	125.44	156.73	69.10	480.00	132.00	2.27
5	5.34	2.16	0.05	0.60	175.62	58.05	254.58	580.00	240.00	1.13
6	4.45	1.90	0.07	0.84	181.89	32.11	85.01	360.00	156.00	5.47
7	4.87	2.93	0.13	1.29	206.98	44.86	130.03	660.00	384.00	1.91
8	5.50	2.35	0.14	0.99	137.98	40.57	134.96	860.00	276.00	1.53
9	4.96	2.59	0.04	0.66	169.34	18.01	56.78	560.00	132.00	1.93
10	5.32	2.40	0.12	1.59	213.25	34.75	408.24	1100.00	276.00	1.84
11	4.22	3.69	0.09	0.81	169.34	30.07	247.97	280.00	96.00	3.83
12	5.24	3.92	0.04	2.43	250.88	23.96	219.63	1160.00	564.00	1.72
13	5.33	3.40	0.08	2.16	244.61	22.69	145.71	1000.00	480.00	1.30
14	4.75	3.58	0.12	1.02	175.62	37.28	355.71	480.00	312.00	4.54
15	5.14	2.95	0.06	0.84	263.42	93.09	195.22	540.00	192.00	0.60
16	4.06	3.90	0.09	0.72	156.80	36.72	196.78	320.00	216.00	8.73
17	4.42	1.99	0.08	2.34	163.07	20.94	113.68	260.00	240.00	2.86
18	5.16	1.87	0.26	2.16	156.80	38.01	327.94	480.00	180.00	1.18
19	4.84	2.74	0.10	2.64	206.98	22.01	85.57	560.00	156.00	4.87
Edavaka Panchayath										
20	4.92	1.92	0.06	2.37	112.90	78.88	43.68	360.00	144.00	3.97
21	4.60	2.67	0.07	2.31	144.26	29.97	87.81	420.00	132.00	2.34
22	3.71	4.28	0.76	2.70	194.43	29.75	204.40	520.00	336.00	1.83
23	4.83	2.38	0.07	2.49	156.80	80.33	64.29	580.00	276.00	1.19
24	4.64	3.62	0.06	2.82	169.34	21.86	68.88	500.00	372.00	1.10

Sample No.	pH	Ex. Acidity (cmol p^+ Kg^{-1})	EC (dSm^{-1})	OC %	N ($Kgha^{-1}$)	P ($Kgha^{-1}$)	K ($Kgha^{-1}$)	Ca ($mgkg^{-1}$)	Mg ($mgkg^{-1}$)	S ($mgkg^{-1}$)
25	4.66	2.80	0.07	2.76	206.98	21.11	65.74	400.00	156.00	1.07
26	5.64	2.53	0.20	2.67	188.16	46.60	727.78	840.00	384.00	1.09
27	4.91	2.93	0.15	1.38	194.43	21.59	69.44	520.00	168.00	5.75
28	4.65	5.03	0.06	1.14	213.25	16.37	150.75	340.00	204.00	4.37
29	5.54	3.60	0.07	0.60	175.62	61.10	185.36	600.00	384.00	1.57
30	4.90	1.27	0.09	0.30	125.44	36.75	37.07	460.00	144.00	4.77
31	4.73	2.52	0.06	0.51	131.71	23.22	36.74	380.00	252.00	0.76
32	5.46	1.66	0.08	0.33	131.71	20.79	78.51	480.00	360.00	2.41
33	5.52	1.45	0.15	1.08	144.26	25.40	471.63	820.00	468.00	1.77
34	4.26	2.07	0.64	1.14	181.89	22.84	360.08	880.00	504.00	6.75
35	4.85	3.43	0.10	1.20	225.79	24.63	213.70	580.00	384.00	1.10
36	4.66	3.73	0.06	0.54	169.34	19.16	71.34	420.00	348.00	2.94
Thirunelly Panchayath										
37	4.81	3.17	0.06	0.60	206.98	51.23	419.10	400.00	180.00	5.61
38	4.11	3.10	0.24	1.05	181.89	39.80	58.24	260.00	180.00	2.00
39	5.61	1.97	0.06	0.99	131.71	31.58	134.74	700.00	264.00	1.91
40	4.64	1.58	0.08	0.54	137.98	17.27	53.87	480.00	276.00	3.49
41	5.92	2.82	0.10	1.05	150.53	18.49	110.32	2860.00	1116.00	1.01
42	5.43	1.31	0.05	0.42	144.26	32.07	186.82	800.00	504.00	1.14
43	5.66	2.82	0.07	0.96	137.98	18.01	75.94	1360.00	1224.00	1.32
44	4.96	2.32	0.06	0.39	150.53	21.66	68.43	300.00	192.00	0.62
45	5.15	2.09	0.06	0.60	144.26	18.12	92.96	820.00	444.00	0.46
Thavinhal Panchayath										
46	5.25	1.03	0.07	0.90	156.80	74.63	208.99	460.00	240.00	1.10
47	5.18	1.93	0.11	0.96	150.53	36.00	222.21	420.00	264.00	1.01
48	5.21	0.55	0.09	0.42	188.16	21.50	64.51	400.00	132.00	0.71
49	4.40	1.01	0.40	0.30	156.80	21.64	142.69	360.00	144.00	0.81
50	4.76	1.29	0.20	1.08	200.70	30.99	203.50	560.00	324.00	3.54
51	5.61	1.18	0.14	0.87	130.71	17.32	115.58	460.00	252.00	0.45

Sample No.	pH	Ex. Acidity (cmol p^+ Kg^{-1})	EC (dSm^{-1})	OC %	N ($Kgha^{-1}$)	P ($Kgha^{-1}$)	K ($Kgha^{-1}$)	Ca ($mgkg^{-1}$)	Mg ($mgkg^{-1}$)	S ($mgkg^{-1}$)
52	5.15	1.25	0.07	0.72	200.70	26.30	78.62	400.00	144.00	1.86
53	4.25	5.01	0.10	1.32	250.88	19.50	95.31	220.00	108.00	2.33
54	4.73	3.14	0.12	1.23	232.06	125.31	375.65	480.00	252.00	0.83
55	4.76	2.99	0.06	0.87	244.61	51.08	276.98	360.00	120.00	0.97
56	4.94	5.19	0.27	2.31	301.06	19.52	407.01	1060.00	300.00	3.00
57	4.91	4.43	0.07	1.44	257.15	18.12	376.99	520.00	228.00	1.12
58	3.73	6.96	0.37	1.14	232.06	29.72	164.08	220.00	180.00	2.78
59	4.85	4.61	0.17	1.17	219.52	44.40	509.26	480.00	276.00	1.45
60	4.50	5.55	0.12	1.23	250.88	18.17	121.30	260.00	276.00	2.00
61	3.94	3.49	0.44	1.05	200.70	20.40	191.97	400.00	132.00	2.79
62	4.70	3.79	0.06	2.04	263.42	24.15	64.96	320.00	84.00	2.81
63	4.23	2.65	0.16	1.05	225.79	29.42	187.94	420.00	132.00	2.16
64	4.36	4.80	0.33	1.29	250.88	18.56	279.66	500.00	252.00	3.38
65	4.65	4.57	0.07	1.20	294.78	18.01	82.10	300.00	168.00	2.89
Thondernadu Panchayath										
66	5.10	3.30	0.08	1.80	313.60	17.20	124.54	820.00	264.00	2.96
67	4.93	4.54	0.09	1.23	225.79	54.69	206.98	580.00	264.00	2.82
68	4.61	3.60	0.15	1.29	250.88	22.25	70.90	320.00	132.00	4.01
69	4.65	4.89	0.06	1.47	275.97	17.36	162.06	400.00	168.00	3.18
70	4.43	5.32	0.05	0.90	238.34	16.68	78.85	260.00	288.00	2.30
71	4.66	4.75	0.26	1.65	232.06	17.85	341.26	640.00	408.00	2.67
72	4.86	5.93	0.07	1.83	250.88	15.85	129.14	420.00	384.00	1.89
73	4.35	5.59	0.11	1.68	244.61	15.96	414.51	260.00	144.00	2.48
74	4.76	5.75	0.26	2.52	238.34	18.51	408.02	740.00	336.00	3.83
75	5.12	3.93	0.18	1.89	275.97	16.33	149.18	1020.00	432.00	5.20
76	4.96	6.92	0.06	2.67	225.79	16.04	108.08	580.00	240.00	1.24
77	4.45	5.23	0.10	1.35	200.70	50.25	306.77	260.00	156.00	7.84
78	4.25	4.95	0.22	2.10	213.25	19.28	697.42	280.00	180.00	3.90
79	5.05	4.30	0.07	1.68	225.79	20.98	95.98	740.00	276.00	4.59

Sample No.	pH	Ex. Acidity (cmol $(p^{+})Kg^{-1}$)	EC (dSm^{-1})	OC (%)	N $(Kgha^{-1})$	P $(Kgha^{-1})$	K $(Kgha^{-1})$	Ca $(mgkg^{-1})$	Mg $(mgkg^{-1})$	S $(mgkg^{-1})$
80	3.95	5.63	0.28	1.71	219.52	183.75	150.08	340.00	96.00	6.45
81	4.61	4.47	0.07	1.56	250.88	133.48	165.87	520.00	120.00	4.54
82	5.00	3.40	0.09	2.07	257.15	23.15	671.22	640.00	276.00	3.30
Vellamunda Panchayath										
83	5.08	4.35	0.07	1.41	244.61	18.84	116.14	400.00	240.00	2.94
84	5.17	1.54	0.12	0.87	200.70	27.06	124.88	600.00	264.00	6.21
85	4.83	3.45	0.05	0.57	175.62	18.93	48.83	320.00	168.00	2.99
86	5.44	0.96	0.09	1.02	163.07	20.26	582.62	620.00	240.00	6.05
87	4.60	4.86	0.18	3.12	332.42	17.66	166.66	520.00	216.00	5.54
88	4.73	2.98	0.08	0.99	188.16	17.23	117.60	580.00	168.00	6.71
89	4.94	1.04	0.07	0.90	163.07	22.67	68.99	420.00	252.00	3.49
90	4.85	0.98	0.05	0.72	144.26	20.90	130.14	440.00	324.00	2.35
91	4.83	3.67	0.06	1.50	244.61	16.72	178.19	720.00	408.00	1.91
92	4.93	3.90	0.11	1.32	238.34	20.19	471.41	980.00	348.00	3.91
93	4.75	6.65	0.13	2.73	263.42	15.43	205.07	820.00	288.00	3.69
94	4.77	2.42	0.09	1.20	244.61	24.67	101.70	560.00	168.00	4.71
95	4.85	2.34	0.07	0.75	213.25	25.01	119.06	420.00	228.00	3.55
96	4.75	2.03	0.08	0.69	169.34	25.45	111.55	380.00	240.00	2.79
97	6.03	3.85	0.17	2.10	238.34	41.26	737.30	1340.00	612.00	5.28
98	5.36	3.89	0.09	1.50	250.88	19.98	125.78	1000.00	504.00	3.36
99	5.16	3.27	0.09	1.53	288.51	18.03	144.93	640.00	420.00	6.04
100	5.13	2.99	0.07	1.26	269.70	21.36	82.21	900.00	300.00	3.65

C. Results of available micro nutrients, Ex. Aluminum, Ex. Sodium, ECEC and acid phosphatase activity (for individual samples

Sample No.	Fe (mg kg^{-1})	Mn (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	B (mg Kg^{-1})	Ex. Na (cmol (p^{+})K $g-^{1}$)	Ex. Al (cmol (p^{+}) Kg^{-1})	ECEC (cmol (p^{+}) $Kg-^{1}$)	Acid phosphatase activity (µg PNP g $soil^{-1}$ h^{-1})
Mananthavady Municipality									
1	130.50	20.85	7.84	1.45	0.10	0.18	1.69	6.56	22.28
2	86.96	38.85	8.03	1.30	0.09	0.23	2.78	8.75	28.51
3	207.20	78.50	6.23	0.84	0.10	0.12	2.89	5.40	26.89
4	170.80	12.32	7.43	0.43	0.09	0.15	1.25	5.13	20.14
5	94.49	68.11	7.57	0.19	0.11	0.14	2.06	7.49	30.45
6	187.50	27.22	9.23	0.74	0.10	0.12	1.80	5.22	27.63
7	40.83	189.70	14.55	0.94	0.10	0.14	2.78	9.72	20.91
8	51.11	118.90	11.25	0.79	0.11	0.13	2.25	9.23	14.36
9	27.29	109.70	3.62	0.45	0.10	0.15	2.39	6.70	17.82
10	84.95	79.74	13.63	0.19	0.09	0.18	2.25	10.84	36.89
11	16.50	29.70	14.11	0.96	0.09	0.13	3.49	6.30	34.15
12	59.39	187.90	5.98	3.27	0.11	0.13	3.82	14.79	23.45
13	67.21	162.00	8.95	0.86	0.10	0.16	3.15	12.72	27.27
14	140.50	41.30	7.49	0.35	0.09	0.15	3.28	9.14	45.89
15	74.99	32.87	6.98	0.20	0.08	0.17	2.80	7.64	32.09
16	90.37	54.88	5.32	0.81	0.09	0.13	3.55	7.65	49.45
17	344.80	40.64	6.07	1.71	0.10	0.18	1.79	5.60	45.86
18	147.40	16.18	7.35	0.86	0.08	0.18	1.62	6.31	40.15
19	217.10	41.19	8.90	1.70	0.09	0.20	2.54	7.14	28.17
Edavaka Panchayth									
20	150.90	17.92	6.70	0.44	0.08	0.16	1.77	5.13	25.89
21	52.18	35.54	7.17	0.64	0.09	0.16	2.57	6.13	22.05
22	118.00	90.65	5.65	0.25	0.09	0.18	3.98	10.09	58.78

Sample No.	Fe (mg kg^{-1})	Mn (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	B (mg Kg^{-1})	Ex. Na (cmol (p^{+})Kg-^{1})	Ex. Al (cmol (p^{+}) Kg^{-1})	ECEC (cmol (p^{+}) Kg-^{1})	Acid phosphatase activity (µg PNP g soil^{-1} h $^{-1}$)
23	86.91	63.33	8.65	0.96	0.11	0.15	2.13	7.80	36.25
24	95.81	53.80	7.28	0.31	0.09	0.18	3.32	9.48	40.91
25	49.72	46.64	9.06	0.16	0.10	0.18	2.60	6.35	32.18
26	93.14	40.14	6.48	11.74	0.12	0.20	2.38	10.95	39.79
27	183.90	73.05	5.69	4.86	0.09	0.20	2.73	7.21	34.15
28	77.36	56.95	8.45	1.68	0.09	0.20	4.78	8.80	26.04
29	172.30	32.87	7.04	0.10	0.09	0.22	3.45	10.23	20.18
30	89.23	52.16	14.64	0.19	0.07	0.19	1.17	5.00	21.34
31	70.36	49.99	5.84	0.53	0.06	0.18	2.42	6.74	30.18
32	51.92	14.37	4.67	0.35	0.05	0.23	1.56	7.37	27.15
33	102.20	66.44	16.50	9.04	0.07	0.17	1.30	10.16	23.23
34	106.80	101.50	7.34	5.46	0.06	0.43	1.82	11.51	42.09
35	77.07	112.30	6.40	8.57	0.08	0.20	3.23	9.96	16.46
36	34.98	52.92	5.71	1.18	0.06	0.24	3.48	9.05	13.45
Thirunelly Panchayath									
37	138.70	17.64	3.84	1.45	0.07	0.21	2.97	7.36	30.18
38	139.20	32.95	6.64	7.35	0.06	0.24	2.80	6.20	24.78
39	119.00	29.47	5.37	0.37	0.08	0.19	1.82	8.02	16.21
40	155.70	17.48	5.00	1.94	0.06	0.22	1.38	6.56	27.65
41	69.76	35.39	6.68	2.19	0.06	0.32	2.72	26.86	12.89
42	132.60	114.60	5.61	1.01	0.06	0.22	1.16	9.95	31.05
43	85.13	39.46	5.61	4.53	0.08	0.29	2.67	20.20	17.56
44	114.60	15.67	5.47	1.27	0.08	0.12	2.12	5.62	20.35
45	76.36	53.44	5.02	1.13	0.08	0.20	1.94	10.19	11.90
Thavinhal Panchayath									
46	115.20	18.84	7.12	5.26	0.09	0.19	0.93	5.76	25.48
47	308.80	37.15	9.23	4.98	0.09	0.23	1.78	6.71	27.96
48	49.51	31.43	5.74	1.23	0.10	0.18	0.50	3.91	14.35
49	58.81	38.65	6.86	0.64	0.08	0.20	0.91	4.38	27.98
50	118.70	61.56	6.03	2.28	0.08	0.21	0.94	7.23	32.74

Sample No.	Fe (mg kg^{-1})	Mn (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	B (mg Kg^{-1})	Ex. Na (cmol (p^{+})Kg-^{1})	Ex. Al (cmol (p^{+}) Kg^{-1})	ECEC (cmol (p^{+}) Kg-^{1})	Acid phosphatase activity (µg PNP g soil^{-1} h $^{-1}$)
51	62.97	22.01	9.15	1.14	0.12	0.20	1.03	5.91	18.69
52	254.60	42.40	7.48	4.95	0.11	0.15	1.15	4.69	14.36
53	78.56	43.60	5.49	8.94	0.11	0.20	4.76	7.32	28.56
54	192.10	14.40	7.71	8.43	0.11	0.28	2.94	8.34	49.69
55	16.48	6.42	7.48	2.64	0.10	0.17	2.74	6.27	42.50
56	29.08	82.80	5.48	0.62	0.08	0.21	4.89	13.65	45.01
57	20.07	71.20	7.24	2.75	0.07	0.21	4.23	9.56	41.20
58	83.99	37.40	7.24	2.90	0.07	0.18	6.56	9.92	48.17
59	108.40	61.40	8.64	4.42	0.08	0.19	4.26	10.08	55.45
60	120.10	21.70	6.72	6.05	0.07	0.19	5.25	9.48	27.96
61	69.30	42.80	4.55	4.43	0.09	0.20	3.24	7.01	35.15
62	142.50	40.10	4.83	3.11	0.09	0.19	3.49	6.35	36.17
63	83.51	62.20	5.84	5.26	0.07	0.20	2.40	6.26	27.16
64	79.84	43.40	8.32	5.83	0.08	0.23	4.50	9.95	38.09
65	66.55	46.50	7.03	3.37	0.09	0.24	4.32	7.80	24.78
Thondernadu Panchayath									
66	66.55	46.50	5.87	4.99	0.10	0.23	3.15	9.98	14.57
67	42.95	40.70	1.96	4.37	0.08	0.21	4.34	10.08	22.36
68	64.57	43.80	5.26	3.35	0.07	0.21	3.45	6.60	20.25
69	88.05	60.80	4.61	5.62	0.08	0.17	4.74	8.65	28.45
70	78.40	55.60	4.96	4.39	0.08	0.22	5.12	9.33	20.45
71	82.45	62.60	7.11	4.55	0.09	0.19	4.50	11.92	38.15
72	220.90	41.20	6.98	6.36	0.08	0.25	5.63	11.62	36.15
73	66.59	23.90	5.72	5.06	0.07	0.17	5.34	8.73	21.89
74	31.53	77.30	6.30	4.88	0.09	0.28	5.55	12.99	40.08
75	49.84	130.00	2.89	6.14	0.08	0.20	3.78	13.00	25.36
76	36.23	71.70	6.80	5.02	0.08	0.20	6.72	12.14	14.32
77	97.28	10.14	6.46	4.22	0.09	0.16	4.98	8.34	19.56
78	95.37	11.90	8.10	4.57	0.09	0.18	4.80	8.83	37.56
79	34.15	41.40	5.77	3.92	0.06	0.23	4.10	10.64	31.26

Sample No.	Fe (mg kg^{-1})	Mn (mg Kg^{-1})	Zn (mg Kg^{-1})	Cu (mg Kg^{-1})	B (mg Kg^{-1})	Ex. Na (cmol (p$^+$)Kg-^{1})	Ex. Al (cmol (p$^+$) Kg^{-1})	ECEC (cmol (p$^+$) Kg-^{1})	Acid phosphatase activity (µg PNP g soil^{-1} h $^{-1}$)
80	20.56	72.10	3.79	3.97	0.07	0.19	5.33	8.49	48.59
81	62.97	33.95	6.32	4.91	0.08	0.21	4.22	8.48	42.36
82	19.46	67.80	6.59	3.84	0.09	0.25	3.25	9.91	32.15
Vellamunda Panchayath									
83	45.21	42.70	4.32	1.77	0.07	0.21	4.15	8.69	24.86
84	72.63	45.30	7.77	5.68	0.06	0.19	1.44	7.08	30.15
85	34.15	39.20	4.04	1.56	0.05	0.21	3.20	6.71	15.96
86	42.99	77.60	6.44	3.93	0.07	0.22	0.91	6.94	28.36
87	177.90	88.00	10.78	7.52	0.08	0.35	4.71	9.80	18.56
88	46.29	59.30	5.50	4.30	0.07	0.23	2.78	7.64	27.69
89	113.40	21.50	4.32	5.27	0.07	0.24	0.94	5.56	32.58
90	68.32	29.80	4.42	3.25	0.08	0.22	0.93	6.25	33.75
91	76.77	42.70	6.19	6.06	0.07	0.28	3.47	11.15	33.97
92	18.69	117.00	28.50	2.44	0.08	0.22	3.65	12.45	29.12
93	39.92	133.00	2.11	2.37	0.06	0.41	6.35	13.79	31.09
94	32.36	9.38	3.67	4.56	0.07	0.30	2.27	7.03	15.24
95	19.45	16.10	3.50	1.84	0.08	0.21	2.24	6.69	19.26
96	22.61	8.56	5.65	2.13	0.06	0.23	1.88	6.28	24.88
97	33.63	108.00	7.09	3.84	0.09	0.26	3.65	16.75	37.18
98	46.79	133.00	6.57	2.31	0.06	0.21	3.64	13.45	30.48
99	34.24	109.00	3.54	2.66	0.07	0.27	3.12	10.40	24.18
100	21.26	90.20	6.30	3.21	0.07	0.21	2.89	10.29	12.48

C. Results of SQI and LQI (for individual samples)

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
Mananthavady	1	225.00	56.25	13.72	1.37
	2	253.00	63.25	27.09	2.71
	3	215.00	53.75	9.90	0.99
	4	228.00	57.00	7.44	0.74
	5	253.00	63.25	13.76	1.38
	6	258.00	64.50	18.74	1.87
	7	265.00	66.25	25.44	2.54
	8	269.00	67.25	19.79	1.98
	9	211.00	52.75	11.67	1.17
	10	304.00	76.00	28.93	2.89
	11	269.00	67.25	17.30	1.73
	12	276.00	69.00	40.96	4.10
	13	264.00	66.00	40.99	4.10
	14	296.00	74.00	17.83	1.78
	15	243.00	60.75	17.34	1.73
	16	249.00	62.25	14.88	1.49
	17	254.00	63.50	53.56	5.36
	18	289.00	72.25	39.20	3.92
	19	248.00	62.00	51.26	5.13
Edavaka	20	260.00	65.00	54.21	5.42
	21	260.00	65.00	42.37	4.24
	22	292.00	73.00	50.31	5.03
	23	259.00	64.75	44.64	4.46
	24	241.00	60.25	51.97	5.20
	25	247.00	61.75	52.82	5.28
	26	323.00	80.75	53.35	5.34
	27	255.00	63.75	23.60	2.36
	28	260.00	65.00	20.86	2.09
	29	263.00	65.75	12.36	1.24
	30	205.00	51.25	5.93	0.59
	31	204.00	51.00	9.73	0.97
	32	203.00	50.75	6.05	0.61
	33	317.00	79.25	20.39	2.04
	34	306.00	76.50	18.30	1.83
	35	277.00	69.25	19.18	1.92
	36	218.00	54.50	9.52	0.95
Thirunelly	37	273.00	68.25	11.71	1.17
	38	260.00	65.00	19.16	1.92
	39	263.00	65.75	22.29	2.23
	40	218.00	54.50	12.18	1.22
	41	274.00	68.50	25.20	2.52
	42	220.00	55.00	8.02	0.80
	43	259.00	64.75	18.02	1.80
	44	189.00	47.25	8.99	0.90
	45	219.00	54.75	13.51	1.35
Thavinhal	46	262.00	65.50	21.41	2.14
	47	262.00	65.50	22.03	2.20
	48	174.00	43.50	8.93	0.89
	49	186.00	46.50	6.44	0.64
	50	238.00	59.50	18.01	1.80
	51	214.00	53.50	13.92	1.39
	52	254.00	63.50	21.70	2.17
	53	288.00	72.00	21.40	2.14

Panchayat/ Muncipality	Sample No.	SQI	RSQI (%)	Soil organic carbon stock (Mg ha^{-1})	LQI (kg m^{-2})
	54	255.00	63.75	14.88	1.49
	55	299.00	74.75	38.88	3.89
	56	277.00	69.25	29.16	2.92
	57	272.00	68.00	23.71	2.37
	58	297.00	74.25	23.42	2.34
	59	260.00	65.00	24.13	2.41
	60	260.00	65.00	22.05	2.21
	61	260.00	65.00	43.59	4.36
	62	272.00	68.00	17.86	1.79
	63	272.00	68.00	21.67	2.17
	64	248.00	62.00	21.42	2.14
	65	250.00	62.50	33.37	3.34
Thomdernadu	66	289.00	72.25	23.83	2.38
	67	248.00	62.00	23.99	2.40
	68	260.00	65.00	26.68	2.67
	69	233.00	58.25	18.50	1.85
	70	299.00	74.75	31.93	3.19
	71	268.00	67.00	36.78	3.68
	72	284.00	71.00	33.17	3.32
	73	299.00	74.75	45.74	4.57
	74	282.00	70.50	36.29	3.63
	75	256.00	64.00	49.03	4.90
	76	303.00	75.75	28.18	2.82
	77	284.00	71.00	41.58	4.16
	78	263.00	65.75	32.23	3.22
	79	279.00	69.75	34.50	3.45
	80	272.00	68.00	32.06	3.21
	81	284.00	71.00	40.92	4.09
	82	248.00	62.00	29.41	2.94
Vellamunda	83	264.00	66.00	17.71	1.77
	84	218.00	54.50	11.71	1.17
	85	291.00	72.75	20.88	2.09
	86	267.00	66.75	67.86	6.79
	87	240.00	60.00	21.98	2.20
	88	233.00	58.25	21.87	2.19
	89	230.00	57.50	14.15	1.41
	90	268.00	67.00	28.92	2.89
	91	299.00	74.75	26.19	2.62
	92	287.00	71.75	56.92	5.69
	93	260.00	65.00	26.64	2.66
	94	230.00	57.50	18.29	1.83
	95	230.00	57.50	14.70	1.47
	96	344.00	86.00	38.79	3.88
	97	275.00	68.75	30.24	3.02
	98	282.00	70.50	31.67	3.17
	99	263.00	65.75	25.83	2.58
	100	225.00	56.25	13.72	1.37

Appendix IV

Soil pH, organic carbon available primary and secondary nutrients, available Zn, available Cu, and available B in the pre-flood soils of Mananthavady block of Wayanad district*

Parameters	Fertility class	Pre flood (Per cent of samples)
pH	Extremely acid	31
	Very strongly acid	29
	Strongly acid	22
	Moderately acid	18
	Slightly acid	-
Organic carbon (%)	Low	10
	Medium	35
	High	55
Available P	Low	31
	Medium	20
	High	49
Available K	Low	25
	Medium	59
	High	16
Available Ca	Adequate	64
	Deficient	34
Available Mg	Adequate	62
	Deficient	38
Available S	Adequate	64
	Deficient	36
Available Zn	Adequate	47
	Deficient	53
Available Cu	Adequate	35
	Deficient	65
Available B	Adequate	93
	Deficient	7

* Kerala State Planning Board (2013)