INTER-REGIONAL DISPARITY IN SOIL FERTILITY STATUS OF SOUTHERN KERALA – A STATISTICAL ANALYSIS

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by

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THESIS

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KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **"Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Vellayani **Nayana Narayanan**

Date: 25-07-2020 (2018-19-001)

CERTIFICATE

Certified that this thesis entitled **"Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis"** is a record of research work done independently by **Ms. Nayana Narayanan (2018-19-001)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Place: Vellayani
Date: 25-07-2020

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We, the undersigned members of the advisory committee of **Ms. Nayana Narayanan (2018-19-001)**, a candidate for the degree of **Master of Science in Agriculture** with major in Agricultural Statistics, agree that the thesis entitled **"Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis"** may be submitted by **Ms. Nayana Narayanan**, in partial fulfilment of the requirement for the degree.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA	Analysis of variance
B	Boron
Ca	Calcium
Cu	Copper
CV	Coefficient of Variation
dS m^{-1}	Desi Siemens per metre
EC	Electrical Conductivity
et al.,	Co-workers
etc.	et cetera
FA	Factor Analysis
Fe	Iron
Fig.	Figure
i.e.	that is
K	Potassium
kg ha^{-1}	Kilogram per hectare
KMO	Kaiser-Meyer-Olkin
MANOVA	Multivariate analysis of variance
Mg	Magnesium
mg kg^{-1}	Milligram per kilogram
Mn	Manganese
No.	Number
OC	Organic Carbon
P	Phosphorus
PC	Principal component
PCA	Principal Component Analysis
S	Sulphur
SFI	Soil Fertility Index
SFI- FA	SFI calculated after factor analysis
SPSS	Statistical Package for Social Sciences
TVPM	Thiruvananthapuram

Introduction

1. INTRODUCTION

India is considered to be the land of diversity with seventh rank in geographical area of 3.28 million km^2. The soil types in India are classified into eight and geographical areas into 15 agro climatic zones and 20 agro ecological regions. Of the total 1.38 billion people 65.97 per cent live in rural India. The livelihood of about 70 per cent of the rural population still remains as agriculture including animal husbandry and fisheries. This implies the importance of agriculture and its allied sectors in a country like India. Agriculture sector contribution to National GDP was estimated as 15.2 per cent in 2017-18. In 2018-19, total food grain production was 283.37 million tones. India is the largest producer of milk, jute and pulses and second largest producer of rice, wheat, sugarcane, cotton, fruits and vegetables.

The state Kerala having 1.18 per cent of India's landmass has the 10th largest economy of the nation and the service sector dominates the Kerala economy. As against 50 per cent of national population depends on agriculture, in Kerala it is around 25 per cent. The most essential crop is rice followed by tapioca, but the production of rice is limited in Kerala. Spices cultivation is also predominant in Kerala, which accounts for about 96 per cent to the total pepper production in the country. Important cash crops cultivated in Kerala are coconut, cashew, tea, coffee, ginger and arecanut. There are ten soil types in Kerala with most common as laterite. Kerala is divided into five agro ecological units as coastal plain, midland plain, foothill, high hill and Palakkad main.

Agriculture sector in India has been facing many challenges like desertification, land degradation, resource intensive agriculture etc. One of the main constraints faced by Indian agriculture is the inadequate use of manures and fertilizers. The reasons for this may be the unawareness of physical, chemical and biological properties of the soils or following a general recommendation in fertilizer application irrespective of regional soil features. As humans need various biological components to sustain life, plants also need various nutrients for their growth and production. According to the quantity of requirement, the total of 17 essential nutrients can be categorized as macro nutrients (those which required in >1ppm) and micronutrients (<1ppm). Among the macro nutrients, carbon, oxygen and hydrogen are absorbed from the air (non mineral essential elements) whereas, commercial fertilizers, manures and soil amendments are the main sources of primary and secondary nutrients. Availability of micro nutrients depends on soil type and pH of soils and some of them can be supplied through fertilizer application also. Both macro and micro nutrients are essential for plant growth. Deficiency of these essential nutrients lead to reduced plant growth and it may express some kind of symptoms. Deficiency symptoms vary with nutrients but in general, for mobile elements like N, P, K and Mg it appears first in mature leaves whereas; it appears in upper, young leaves in the case of micro nutrients. So, an idea about the availability of macronutrients and micronutrients of a region is essential in attaining optimum crop production. In general soil fertility of a region can be assessed from the available soil nutrients like, pH, EC, primary nutrients, secondary nutrients and micronutrients. Analyzing the availability of soil nutrients help in understanding which all nutrients are deficient and which all are adequate in a particular region. The inter-regional variation in soil fertility provides an indication in the deficiency or availability of each of these nutrients and a need based recommendation of fertilizers can be given to that region. Regions can be grouped based on the similarity in fertility status and a general recommendation can be given to these similar regions also. Grouping of the regions based on overall soil fertility is rather good as compared to those using individual soil parameters. Since the soil fertility is not directly measurable, several measurable indicators can be used to quantify this latent variable (Whitmore, 2012). Hence a specialized average called index can be used to quantify the latent variable, soil fertility (Crossman, 2019).

Indices can be constructed as simple aggregation of indicators or weighted aggregation of indicators or by any of the statistical methods (Mukherjee and Lal, 2014) like Principal Component Analysis (PCA). Even a single indicator itself can be considered as an index. Among all these methods, index construction by PCA was found to be more accurate because the weight assigned in this method is based on the variance of the components.

In order to construct soil fertility index (SFI), the indicators required are available soil content of various nutrient parameters and regions in a district are considered as panchayats. The PCA on the mean vector data of soil parameters corresponding to various panchayats will extract a number of principal components based on KMO criteria. From this principal component scores can be estimated by multiplying the mean vector of parameters with the coefficients of extracted PCs. The SFI can be calculated as the weighted aggregation of these principal component scores, where weights are derived as the proportion of variance explained by each PC to the cumulative variance of the extracted PCs. Since the SFI values may show large variation, it is recommended to normalize the SFI prior to classification. SFI can also be constructed by considering only the most relevant parameters of soil fertility and it can be achieved by the use of a multivariate technique known as factor analysis. From all the parameters selected initially, only those which were reported to have high factor loadings on all the extracted factors and high communality can be considered for SFI construction. In this context the present study entitled ‘Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis’ was undertaken with the following objective.

- Develop soil fertility status index to assess regional disparity among the panchayats of Thiruvananthapuram, Kollam and Pathanamthitta districts of southern Kerala and to classify the panchayats based on soil fertility index.

In the present study an attempt was made to construct SFI corresponds to 43 panchayats of Kollam, 50 panchayats of Pathanamthitta and 37 panchayats of Thiruvananthapuram using the method of PCA followed by classification of panchayats into fertility classes of low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%). For this, secondary data on 12 soil fertility parameters namely, pH, EC, OC, P, K, Ca, Mg, S, B, Cu, Fe and Mn collected as a part of Kerala State Planning Board Project conducted in 2013 were used for the analysis. After estimating the SFI, they were normalized by min- max normalization technique and this normalized index was used for the classification.

1.1 SCOPE OF THE STUDY

Construction of SFI will help in understanding the relative fertility of each panchayat with respect to others. So that, importance can be given in improving the soil fertility of the low fertile panchayats and to provide a region based fertilizer recommendation. Also, the classification facilitates a common fertilizer recommendation to similar panchayats. This will help to reduce the problem of improper fertilizer application to a great extent.

1.2 LIMITATION OF THE STUDY

Since the data on soil fertility parameters of all the panchayats were not available, SFI couldn't construct all the panchayats. Data used in the present study was of 2013 only. It was because that, the data recording of the post flood period was not yet complete and that of pre flood period at the same time point were not available for all the panchayats since 2014.

1.3 PRESENTATION OF THE THESIS

The present study contains five chapters namely, introduction, review of literature, materials and methods, results and discussion and summary. In the first chapter introduction, the importance, objectives, scope, limitations and future aspects of the present study are included. Review of the past works related to the current study is included in the second chapter. Third chapter describes various statistical methods and techniques used to analyse the data. The inferences drawn from the analysis are explained in the fourth chapter, results and discussion. Summary of the entire research is presented in the last chapter followed by references and abstract.

1.4 FUTURE LINE OF THE STUDY

The present study is limited to three southern districts of Kerala. This can be further extended to remaining districts and at different time periods to assess or understand temporal variation in soil fertility status. A comparison of soil fertility in the pre and post flood period is also possible with the construction of SFI. Moreover, studies related to nutritional status of soils under various cropping systems also provide an idea about the need based nutrient application or recommendation of crops for different regions.

Review of literature

2. REVIEW OF LITERATURE

The present study on soil fertility index construction by multivariate technique was supported by the studies conducted earlier on principal component analysis, factor analysis and index construction. The reviews of the studies that were useful for effectively doing the present research are presented under two subheadings in this section.

2.1 Importance of principal component analysis and factor analysis

2.2 Indices to measure latent variables

2.1 IMPORTANCE OF PRINCIPAL COMPONENT ANALYSIS AND FACTOR ANALYSIS

Garten (1978) studied multivariate perspectives on the ecology of plant mineral element composition. Mineral element concentration in plants is the result of interaction between genotype and environment. From discriminant analysis it was revealed that there exists a considerable variation in concentration of elements among the species. To study inter element correlation, 110 plant species were analysed using principal component analysis. Four principal components were extracted. First principal component shows correlation between P, N, Cu, S and Fe. Second principal component depicted correlation between Mg, Ca and Mn concentrations and correlation between Mn, K, and Mg was explained by the third principal component.

A study on soil landscape parameters using the application of principal component analysis was performed by Hammer *et al*. (1990). The data set in the present analysis consists of chemical and physical properties of soils of Tennessee. Both factor analysis and principal component analysis were used to summarize the data by reducing the dimension in an acceptable way. Principal component analysis was performed using SYSTAT software and factor analysis results were obtained from SAS. The study has also explained the criteria for factor extraction and variable retention.

Wick *et al*. (1998) analysed soil quality under improved fallow management systems using soil microbiological parameters as indicators at south-western Nigeria. Samples were collected from three locations namely, WB 1, D 2 and WB 3 which differ in soil degradation. Soil parameters related to physical, chemical and biological properties were used in the analysis. Principal component analysis was performed on 17 soil parameters using SYSTAT and the results of the analysis found that three factors namely, soil organic matter related nutrient status, phosphorus component and clay component were the major soil factors which determine variation in productivity of soils.

Facchinelli *et al.* (2001) studied multivariate statistical and GIS-based approach to identify heavy metal sources in soils. Heavy metals like Cr, Co, Ni, Cu, Zn and Pb were studied with the aim of understanding the regional concentration and variability of these heavy metals and to identify their sources of origin as natural or artificial. Principal component analysis and cluster analysis were made use in conducting the study. In addition to these, regional distribution maps were constructed using geostatistics. 98 soil samples were collected and analysis was performed. Three principal components which account for 85 percent of total variation were considered. Analysis concluded that the metals Cr, Co and Ni were mostly associated with soil parent rocks whereas; Cu, Zn and Pb were contributed significantly by anthropogenic sources. GIS software was found to be useful in confirming the results of statistical analysis.

Guler *et al.* (2002) performed multivariate statistical and graphical methods for classification of water chemistry data in Southwestern USA, with the aim to group the water samples into different clusters. Clustering was based on 11 water chemistry variables from 118 spring water samples. The methods used for analyzing and classification of collected data include cluster analysis, PCA, Fuzzy-K means clustering and several graphical methods. Moreover, graphical analysis was performed using raw data, whereas cluster analysis and PCA were done on log transformed and standardized data. Q- mode classification and Euclidian distance was the similarity measure used for clustering. As a result, the samples were grouped into three main groups and nine subgroups. The study concluded that combined use of graphical and multivariate statistical methods will provide better results for analysis and classification of data.

Sena *et al*. (2002) used principal component analysis to study the difference of management effects on soil parameters in Sao Paulo state of Brazil. The study considered three management practices, namely conventional methods which use pesticides and fertilizers, alternative systems using crop residues and effective microorganisms and forest areas using eight soil parameters. These practices were analysed using multivariate statistical techniques like principal component analysis and hierarchical cluster analysis for their influence on soil quality. From the study it was concluded that higher microbial mass was present in the forest area and in alternative plots compared to conventional plots.

Factor analysis as a toll in ground water quality management in southern Africa was performed by Love *et al.* (2004). This study deals with the use of R-mode factor analysis to assess the quality of groundwater. Two case studies were performed. For that samples were taken from two locations. One was from near the iron ore mine and the other was from near municipal sewage disposal works. Total dissolved solids, temperature, faecal coli-forms, total phosphorous, ortho-phosphate, nitrate, p^H, iron, cadmium, total chromium, nickel, copper, lead and zinc were the parameters used for analyzing water quality. R-mode factor analysis was performed with software STATISTICA. Factor analysis distinguished samples from first case study into uncontaminated groundwater, ground water contaminated with agricultural activities and groundwater contaminated with mining activities. In the second case study, ground water samples were recognized with contamination due to sewage works. Study concluded that even though R-mode factor analysis is not a perfect method for ground water quality checking, it can be used for quality assessment.

Boruvka *et al.* (2005) used principal component analysis to identify how much the geogenic and anthropogenic sources contribute to the concentration of some of the Potentially Toxic Elements (PTE) in the soil. Soils of 14 forested sites of Czech Republic with the parameters like Be, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn were used in the present analysis. Principal component analysis was the method used and to support PCA results, element speciation, profile distribution assessment and local geology were also used. From the analysis it was found that Co, Cr, Ni, Be, Cu and Zn were of geogenic origin, whereas for Pb, Hg and Cd there was more anthropogenic contribution compared to that of nature. It was also enlightened from this study that, PCA along with other relevant information provide accurate ideas on the source of Potentially Toxic Elements.

Fox and Metla (2005) studied soil property analysis using, soil line, regression models and principal components analysis with an aim to compare the techniques like principal component analysis, regression model and soil line Euclidean distance in the aspect of estimating relationship between surface soil properties and remotely sensed images. Soil properties taken under consideration in this study were organic matter and CEC. Five bare soil images captured using digital aerial photography systems were also used in the present analysis. The comparative analysis suggested that PCA technique is powerful for spatial heterogeneity detection, whereas soil line Euclidean distance can be effectively used in field specific soil conditions. Moreover, the first principal component showed high correlation with organic matter and CEC for a single image.

Shukla *et al*. (2005) determined soil quality indicators by factor analysis. Quality of a soil can be expressed in terms of physical, chemical and biological soil properties and that are called Soil Quality Indicators (SQI). The present study mainly focused on the use of factor analysis for identifying soil quality indicators and also to assess how the land use patterns and landscape positions influence the SQI. The location for the study was North Appalachian Experimental Watershed (NAEW) in Appalachian Mountains. Analysis was conducted for five land use and management practices. Samples were taken from 0-10 cm and 10-20 cm depths. Factor analysis was performed and multiple comparisons of treatments were done with Bonferroni t-test. Factor analysis grouped 20 soil attributes into five factors for 0-10 cm depth and four factors for 10-20 cm depth. The study revealed that soil organic carbon is the best attribute for soil quality monitoring.

Ringer (2008) studied principal component analysis as a mathematical algorithm to reduce the dimension of data. PCA also enables us to visually assess the relations between the samples followed by possible grouping. In the present study gene expression data were used to explore the applications of PCA.

Cu *et al*. (2009) conducted a study to explore the relation between land use and solid waste generation by applying PCA in the Duy Tien district, Ha Nam Province, Vietnam. Source of the data was Centre for Applied Research in Remote sensing and GIS (CARGIS) and area of the study consists of 19 communes and two small towns with variables as non–farming income/agriculture, tertiary sector/agriculture and non-farming income/built-up zone expansion. PCA was done using SPSS and results were presented using cartography of factor scores obtained from PCA. Kaiser-Mayer-Olkin (KMO), Kaiser’s rule and Varimax were used for obtaining the rotated factor scors. The study concluded that there exists a positive relation between the quantity of waste generated in a locality and its function.

Pejman *et al.* (2009) performed evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques with an aim to examine the quality of water from eight different sampling locations of Haraz river basin and to assess their similarities and dissimilarities based on 10 parameters for four different climatic seasons. Statistical analysis was performed using STATISTICA and Microsoft office excel and the techniques adopted were principal component analysis, cluster analysis and factor analysis. By cluster analysis, eight sampling sites were grouped into three clusters and further the study identified natural parameters like inorganic parameters and organic nutrients as the major sources that contribute to water quality changes in all the seasons.

Valladares *et al*. (2009) made an analysis on the concentration of heavy metals in the vineyard regions of Sao Paulo state of Brazil. Cu, Fe, Mn, Zn, Ni, Pb, Cr and Cd were the heavy metals considered for the present study and samples from both surface and subsurface layer of soils were analysed separately by PCA. Analysis by PCA made it possible to represent each sample in a bi/tridimensional graph. From the loadings of the elements on the PCs, it was clear that there is soil contamination in the vineyards by Cu and Zn.

Abdi and Williams (2010) studied principal component analysis, one of the most widely used and oldest multivariate statistical methods, which is mainly used for dimensionality reduction purposes by summarizing the raw data consisting of several dependent variables into new sets of variables known as principal components. Principal components are chosen by making use of eigen decomposition and the selected components will together contribute to a major fraction of total variation in the data set. In addition to this, in order to deal with qualitative variables, correspondence analysis which is a generalization of principal component analysis is used. Multiple factor analysis is also a generalization of PCA for heterogeneous sets of variables.

Marcinkonis *et al*. (2011) studied extraction and mapping of soil factors using geospatial analysis and factor analysis on intensively manured heterogeneous soils in Lithuania with an objective to determine the variation in the concentrations of soil organic carbon and heavy metals in agricultural lands. Descriptive statistics of soil parameters revealed significant variation in the soil organic carbon and heavy metal concentrations in 33 soil sampling sites. Factor analysis extracted two factors which accounted for about 79% of total variation. Geospatial interpolation was done using Kriging methods and the results of the analysis suggested that Ni, Zn, Pb, and Cu concentrations are the major parameters related to soil parent material.

Niu *et al*. (2011) preferred PCA technique to evaluate degradation of black soil in Jilin. The original 13 variables were replaced by six principal components. From the analysis it was found that soluble salt content, fulvic acids and aggregation degrees are having major influence on black soil degradation.

Anxiang *et al*. (2012) performed multivariate and geostatistical analysis of the spatial distribution and origin of heavy metals in agricultural soils in Shunyi, Beijing, China. Analysis was performed to assess the concentration and sources of heavy metals in soil samples collected from Shunyi district. 412 soil samples were analysed for Cu, Cd, Hg, Zn, Pb and As. Statistical analysis was performed using SPSS. Analysis of variance and principal component analysis were the statistical tools used. Study found that, even though the concentration of these heavy metals in the sample soils was larger than the basic value, it is not big enough to trigger pollution. As and Pb are coming mainly from parent rock whereas, for Cd, Cu and Zn, fertilizers and manures are the major sources. Atmospheric deposition is the source of Hg.

Bansod *et al.* (2012) performed analysis and delineation of spatial variability using geo-sensed apparent electrical conductivity and clustering techniques. Present study made use of techniques like principal component analysis and clustering analysis to analyze the soil variations based on electrical conductivity data. Electrical conductivity, crop yield and nutrient rates were considered as spatial variability representatives of soil. Clustering algorithms adopted were hierarchical clustering and fuzzy c-means clustering. To determine optimum number of zones, Fuzzy Performance Index (FPI) and Normalized Classification Entropy (NCE) indices were adopted.

Harshneet (2012) conducted a study on multivariate characterization of soil fertility and environmental status of two benchmark soils of Punjab. Two study areas were selected, which represents two benchmark soil series- Gehri Bhagi and Nabha of Punjab state. Surface soil samples were collected from 50 locations in each study area. Parameters like pH, EC, organic carbon, available K, available S, Zn, Cu, Fe, Mn, Co, Pb, Cd, Cr and particle size distribution were analysed. PCA loadings were given to each of these parameters. K means cluster analysis was performed on the data. For

Gehri Bhagi soil, four clusters were obtained based on soil excavation for brick kiln purpose and macronutrient content. In the Nabha soil series also four clusters were obtained. Here grouping was based on soil excavation for brick kiln purpose, K and micronutrient content.

A study on principal component analysis for the characterization in the application of some soil properties was performed by Panishkan *et al.* (2012). Principal component analysis was adopted as a technique to classify 67 soil samples collected from three main agricultural areas namely horticulture, field crops and wetland areas in Thailand. Soils were studied for six main properties. By performing PCA, two principal components which accounted around 72% of total variation were selected. The present study helped in concluding that agricultural areas and soil properties show some kind of relationship.

Principal component analysis was used to develop the geochemistry of soil and till deposit developed in Northern Ireland based on 3836 soil samples by Dempster *et al*. (2013). Chemical Index of Alteration (CIA) was used to study the weathering aspects. Principal component analysis of normalized data was performed with 28 soil elements and the first two principal components showed more variation in the data set. The study concluded that the weathering process has no significant role in soil geochemistry and major part of the till deposits derived locally.

Application of multivariate statistical analysis concept was used for the assessment of hydro geochemistry of groundwater in Suri 1 and 2 blocks of Birbhum district, West Bengal, India by Das and Nag (2015). Residents of these areas mainly depend on groundwater for drinking and other domestic purposes. The major emphasis of the study was to identify the natural and anthropogenic factors which are responsible for contamination and quality deterioration of ground water in these areas, using ground water samples collected during pre-monsoon and post-monsoon periods from 26 sampling locations. On the basis of 16 water quality parameters, correlation analysis, hierarchical cluster analysis, principal component analysis and factor analysis were done using the software StatistiXL. Correlation analysis was performed for all the parameters. Squared Euclidean distance was used as the similarity measure in clustering and varimax rotation was used to obtain rotated factor scores.

Multivariate statistical methods like principal component analysis and cluster analysis were done to study the support of regionalization of flow by Elesbon *et al*. (2015). The study focused on grouping of hydrologically homogenous regions of Doce river basin of Brazil based on the data consisting of eight dependent variables and seven independent variables. The two principal components explained about 77% of total variation were took into the account of six independent variables. Four hydrologically homogenous regions were identified by the application of farthest neighbor approach in cluster analysis.

Factor analysis of soil spatial variability in Akoko region of Ondo state, Nigeria was done by Olorunlana (2015). Both natural variation and human activity play significant role as sources of spatial variability of soils. Present study dealt with analyzing spatial variability of soils. Even though the descriptive statistics account for variation analysis, it cannot give an idea about the sources of variation. Soil samples were analysed based on ten physico-chemical properties using descriptive statistics and factor analysis. Four factors which contributed about 78% of the total variation were selected and it indicated that organic matter, chemical properties and textural characteristics contributed more to soil spatial variability.

Factor analysis of rock, soil and water geochemical data from Salem magnesite mines and surrounding area, Salem, southern India was performed by Satyanarayanan *et al*. (2016). Analysis was performed for samples taken from magnesite mining areas of Salem which consists of 34 soil samples, 55 groundwater samples and 15 rock samples. Factor analysis was performed using SPSS. Three factors from rock samples, six factors for soil samples, five factors for ground water during summer and six factors for ground water during winter were chosen. It was revealed from this study that ground water is abundant in minor and trace elements and total dissolved solids in groundwater were coming mainly from rock and mining wastes.

Arias *et al.* (2017) studied homogenization of soil properties map by PCA to define index of agricultural insurance policies. This study was reliant on the development of indices for crop losses, for providing indemnities to farmers according to the indices and for reducing the agricultural risks. Indices can be of vegetation indices or climatic indices. Most commonly used one is the normalized difference vegetation index (NDVI). Moreover, the study aims to develop a map for the rice and maize cultivation areas of Ecuador representing homogeneous classes, which will form the basis for index based crop insurance. Homogenization of areas was done on the basis of soil characteristics, temperature and precipitation. A control map, a categorical map and a factorial map were developed for the region, where the factorial map was a result of PCA and hierarchical cluster analysis. By analyzing these maps, it was found that factorial map assembles more homogenous classes than climatic map and fewer homogenous classes than control maps but it retains the information regarding soil variability.

Multivariate statistical analysis for the identification of potential seafood spoilage indicators was performed by Kuuliala *et al*. (2017) with an objective to statistically analyze the volatile organic compounds in stored foods and also to identify the spoilage indicators. Hierarchical Cluster Analysis (HCA), Principal Component Analysis (PCA) and partial least squares regression analysis were performed and cluster analysis was done using Euclidean distance in R software. The parameters like acetic acid, 2,3- butanediol, methyl-1-butanol, ethyl acetate and trimethylamine were the spoilage indicators of the selected seafoods. This analysis helped in developing better packaging methods.

Muhsina (2018) conducted a study on multivariate analysis for the classification of locations using soil parameters in central districts of Kerala. Location of study was Ernakulam and Kottayam districts of Kerala. The study was based on 13 soil fertility parameters. Descriptive statistics, MANOVA, PCA, factor analysis and cluster analysis were the statistical methods used to analyse the data. SPSS and STATA were the softwares used for the analysis.

2.2 INDICES TO MEASURE LATENT VARIABLES

Deepa (1995) made an investigation about the fertility status of RARS, Pattambi to study the surface soil samples collected from 22 blocks and were analysed for the parameters like OC, P, K, Ca, Mg, Na and Fe. Nutrient index was worked out for each of the parameters and based on the results obtained, the blocks were categorized into fertility classes of low, medium and high and a fertility map of RARS was prepared.

A study on a fertility index for submerged rice soils was studied by Sahrawat and Narteh (2002) with an objective to assess the fertility status of wetland rice soils in

West Africa. The study revealed that soil solution of EC after four weeks of flooding was highly correlated with the concentration of nutrient elements in the solution and thus EC was considered as an index of fertility status.

Abeyasekera (2005) emphasized the role of multivariate methods in the construction of indices to explore the patterns in the data, to classify the data points and to reduce the dimension of the original data set. An index that can be generally represented by the form, $I = a_1X_1 + a_2X_2 + \ldots + a_pX_p$, where a_is are weights assigned to corresponding X_is which can be determined either by regression modelling or by PCA based on the objective of the index construction. The study also revealed that the first principal component of PCA can itself be regarded as a summary index of the data and it is recommended to retain only those variables of the principal component coefficient, greater than 0.5 in the final index.

Water quality assessment of Gomti River in India using multivariate statistical techniques was performed by Singh *et al.* (2005) on the basis of 13 parameters of water samples collected from eight different sites on the Gomti river basin. Discriminant analysis was performed with raw data and cluster analysis, factor analysis and principal component analysis were performed on standardized data and finally eight sites were grouped into three different clusters. The results of the analysis identified soil weathering, leaching and runoff, municipal and industrial waste water and waste disposal site leaching as the main sources of quality determination of river water.

Kenkel (2006) has done a comparative analysis with an objective to select an appropriate multivariate analysis based on three types of data. The three types of data structures considered are namely, continuous abiotic survey data, continuous biotic survey data and categorical contingency data and the analysis methods used were PCA, correspondence analysis and non-metric multidimensional scaling and it was found that principal component analysis was the best for abiotic and biotic survey data and correspondence analysis was best for contingency data.

Meena *et al*. (2006) analyzed the status of macro and micronutrients in some of the soils of Tonk district of Rajasthan using soil samples collected from 120 sites of 26 Gram Panchayats. Soil nutrient indices were developed for the nutrients separately and soils were categorized into low, medium and high in fertility based on the index value.

It was found that soils of the study area were medium in Nitrogen and Phosphorous fertility and high in Potassium fertility.

Zheng *et al*. (2008) evaluated soil fertility of shelter forest land along Tarim desert highway. Soil samples were collected from different soil layers and soil fertility was evaluated by integrated fertility index (IFI). It was found that the shelter forest construction has improved soil physical structure, soil porosity and water holding capacity. It was also evident that the fertility index of the forest was increased with forest age.

In order to examine the soil quality of Zhangjiagang country using three indicator methods namely total data set, minimum data set and Delphi data set was used by Yanbing *et al*. (2009). The two index models used and studied here were integrated quality index and Nemoro quality index. 431 soil samples were collected for the study and found that the minimum data set was the best indicator method compared to the other two methods used and the integrated quality index was better as compared to Nemoro quality index. Combination of minimum data set and integrated quality index is sufficient to measure soil quality adequately.

Application of PCA in constructing socioeconomic index was studied by Krishnan (2010). PCA based index was constructed based on census data from Alberta in order to envisage the socioeconomic status of different regions. Five principal components which explained 56 per cent variation in the data were extracted to represent 26 indicators. This study is a ratification of the ability of PCA to remain less affected by socioeconomic landscape changes.

Trend in fertility status of Indian soils was studied by Pathak (2010) to assess the changing pattern in the fertility status of Indian soils with the data at the time periods 1967, 1977 and 1997 and a nutrient index was constructed by giving weights to low, medium and high groups. From the analysis it was concluded that there was not much decline in the fertility of Indian soils over these years.

A case study on the use of soil fertility index to evaluate two different sampling schemes in soil fertility mapping in Hvanneyri, Iceland was performed by Nketia (2011). Objective of the study was to construct a map on soil fertility to understand the spatial variability in soil nutrient distribution. Soil samples were taken by systematic and random sampling methods. Total soil Carbon, Nitrogen, soil KCl, extractable nitrogen ions, soil pH, biomass carbon, temperature and rainfall, metabolic quotient and soil moisture content were identified as soil fertility indicators. To understand the statistical difference between the sampling schemes one-way ANOVA was performed. In order to develop fertility index, soil fertility indicators were transformed into score values. This study has made use of GIS for analysis and interpreting spatial data. Maps were constructed using GIS for better nutrient management. Study concluded that more samples and parameters to be estimated must be taken for getting precise results. Systematic sampling was more precise than randomized sampling for assessing spatial variability based on fertility index.

Panwar *et al.* (2011) studied soil fertility index, soil evaluation index and microbial indices under different land uses in acidic soil of humid subtropical India. This study focused on comparing the quality of soils based on physicochemical, chemical and biological indicators of the soils under study. Here soils from three land use practices namely home garden, arecanut plantation and agricultural land use were compared with that from forest. Parameters like pH, Organic Carbon, electrical conductivity, cation exchange capacity, available Nitrogen, Phosphorous, exchangeable Calcium, Magnesium, Potassium, Aluminium, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and dehydrogenase activity were examined to study soil fertility. Soil fertility index (SFI) and soil evaluation factor (SEF) were developed to quantify soil fertility. From the study it was revealed that forest possess greater fertility index followed by arecanut plantation, home garden and agricultural land respectively. In the case of soil evaluation factor, the same trend is followed.

Tao *et al.* (2012) constructed a composite sustainability index of the manufacturing industry using PCA. Indicators from environmental, social and economic dimensions were considered for index construction. 11 manufacturing companies across the world were investigated via the constructed index using 12 indicators. Five principal components which accounted for 93.2 percent variation in the data were used for index construction.

Whitmore (2012) performed statistical analysis to rank the UN member countries in relation to an index developed on the basis of the E- Government programme. Factor analysis was the method adopted to identify the indicators used in the index construction. The E- Government index prevailed was, I = 0.34 (Online service index) + 0.33 (telecommunication infrastructure index) + 0.33 (Human capital index). Each of these component indices itself is related to 11 indicators related to it. The present study found that among the 11 raw data measures, the indicator 'mobile subscribers' could be eliminated and the empirically derived weights through factor analysis can be used rather than the deterministic weights.

Mazziotta and Pareto (2013) provided guidelines to construct a composite index to measure the socio economic development which needs the aggregation of several indicator variables. Moreover, it indicated that data normalization is an important step to be considered while aggregating the indicators of different units and also it is recommended to exempt those indicators which are highly correlated.

Soil fertility status and correlation of available macro and micronutrients in the Chambal region of Madhya Pradesh was studied by Singh *et al*. (2014) using 100 soil samples data. Soils were rated as low, medium and high in fertility based on the nutrient indices constructed.

The PCA based socio economic status index was constructed for Brazil and Ethiopia by Vyas and Kumaranayake (2014) using data from Demographic Health Survey (DHS). Separate indices for rural and urban locations were constructed for both the countries followed by grouping of households into various socio-economic classes.

A study on deficiency of micronutrients and Sulphur in soils of Chittoor district of Andhra Pradesh was done by Govardhan (2015) based on 576 soil samples in order to delineate a GIS based soil fertility map. Fertility status of each parameter was identified through the construction of nutrient index. It was clear from the study that about 18.6 per cent of total soil samples suffered from micronutrient deficiencies.

Kavitha and Sujatha (2015) conducted a study on evaluation of soil fertility status in various agro ecosystems of Thrissur district, Kerala, India. The objective of the study was to evaluate the soil fertility status in the eight major agro ecosystems viz. coconut, banana, rubber, paddy, arecanut, nutmeg, pepper and vegetables. Soil samples were collected from 30 Panchayats of the Thrissur district which represent six agro ecological zones in the district. pH, EC, organic carbon, macro and micro nutrients of selected samples were estimated and nutrient index was calculated. Descriptive Statistics and analysis of variance using Duncan's multiple range were the statistical tools used to analyse the collected data. Relationship between selected soil properties was estimated using correlation analysis. The study revealed that the status of N, P and K was high in rubber. In arecanut plantations there had a deficiency of K but S was deficient in rubber, vegetables and pepper.

Navarro *et al.* (2015) conducted a study to develop an index and to identify the parameters which influence the soil quality of Mediterranean ecosystems using several physical as well as biochemical attributes governing the soil quality. Application of PCA on this data enabled it to identify the limiting parameters of soil quality followed by index construction. This index is useful to depict the variation in soil quality ostensibly.

Persic and Wagner (2015) conducted a study to analyse the Croatian regional disparity based on five socio- economic indicators. Two types of composite indices were constructed. They were I_c^v based on unit weights and I_c^{PCA} computed using PCA. The study revealed that PCA categorization was more relevant as compared to categorization using I_c^v.

Yamini (2015) conducted a study on fertility evaluation of tobacco growing soils of Prakasam district of Andhra Pradesh. 100 soil samples were collected from the region and analysed its physical, physio-chemical, available macro and micro nutrient status. Correlation between different soil properties were analysed with the help of SPSS software. Through the development of nutrient index, the study analysed that the soils were low in N, medium in P and high in K and S. Among the total samples, 89 per cent of soils were highly suitable and 11 per cent were suitable for tobacco cultivation.

Assessment of soil fertility status using nutrient index approach was done by Amara *et al.* (2017). Objective of the study was to assess the fertility variation in soils by using nutrient index and fertility rating. Five villages within the Bogur micro-watershed of Karnataka state were taken for the study. 118 soil samples were analysed for the physicochemical properties which include pH, electrical conductivity, available major nutrients and micronutrients. Nutrient index was constructed to compare fertility status among the locations under study. According to the Nutrient Index Value (NIV) fertility status were rated as low (NIV$<$ 1.67), medium (NIV between 1.67-2.33) and high (NIV$>$ 2.33). This study concluded that pH, available Nitrogen, available Potassium and available Sulphur were low to medium, electrical conductivity, available

Zn and available Fe were low, organic Carbon and exchangeable Magnesium were high, exchangeable Calcium was medium and available Phosphorous was medium to high in fertility rating of the study areas. Study identified pH, available N, K, S, Zn and Fe as main fertility constraints to crop production

Assessment of soil fertility status of Mid Himalayan region, Himachal Pradesh was performed by Annepu *et al.* (2017) with an objective to assess the fertility status of soils of the Mid Himalayan region using soil fertility index. The analysis was done with parameters like soil color, pH, texture, electrical conductivity, Organic Carbon and available macro and micronutrients from 250 soil samples and a soil fertility index was developed to estimate soil fertility status. The nutrient index developed showed that soils were medium in fertility for all available macronutrients and Organic Carbon showed a significant positive correlation with availability of essential plant nutrients and available Potassium and phosphorus.

Khadka *et al*. (2017) evaluated soil fertility status of RARS, Tarahara, Sunsari, Nepal. 81 soil samples were collected and analysed for parameters like texture, structure, colour, pH, organic matter, N, $P_2O_{5,}$, K_2O, Ca, Mg, S, B, Fe, Zn, Cu and Mn. Statistical analysis method used was descriptive Statistics. Estimated values were rated into very low, low, medium, high and very high. Nutrient index was also developed for the region. This study conveyed the importance of proper nutrient management during cultivation.

Khaki *et al.* (2017) compared two types of soil fertility indexes to evaluate paddy fields for rice cultivation in Northern Iran. The index for the paddy field was developed by square root method and joint fuzzy membership functions as fuzzy methods and also constructed a fertility map for the study area. It indicated that drainage and thickness of the plow layer were the most important limiting factors for paddy production and the fuzzy method was the best method.

Stamenkovic and Savic (2017) analysed regional economic disparities in Serbia based on five economic indicators by the method of multivariate statistical analysis. Composite indices of economic development were constructed using factor analysis. Normalization of indicators were done before applying factor analysis. Based on the indices constructed, grouping of districts were done. As a result, the districts were categorized into three groups.

Assessment of soil fertility index for potato production using integrated fuzzy and AHP approaches, Northeast of Iran was performed by Bagherzadeh *et al*. (2018). Based on the fertility index value, study areas were classified into very low, low and moderately fertile and the results identified with low Organic Carbon and low mineral Nitrogen as the reasons for low soil fertility in the study area.

Soil fertility evaluation for macronutrient using Parker's nutrient index approach of Varanasi district of eastern Uttar Pradesh, India was performed by Singh *et al*. (2018). 30 soil samples were collected from four blocks of the district and the samples were analyzed for pH, electrical conductivity, Organic Carbon, Nitrogen, Phosphorus and Potassium. The sampling locations were categorized into low, medium and high in fertility status based on the index developed.

The reviews so far incorporated and narrated in the present chapter underline the use of index to measure a phenomenon that can't be expressed quantitatively. Moreover, this chapter explained about the various indices and their method of construction, inclusion of indicators for index construction and finally emphasizes the importance of PCA based index and its advantages. On the basis of the conclusion based on the reviews, an attempt was made to quantify the soil fertility status, not possible to measure directly but by constructing an index using different soil fertility indicators.

Materials and Methods

3. MATERIALS AND METHODS

The aim of the present study is to construct an index to assess the soil fertility status of different panchayats of Kollam, Pathanamthitta and Thiruvananthapuram districts of southern Kerala. The analysis is based on secondary data of twelve soil fertility parameters collected as a part of Kerala State Planning Board Project conducted in 2013. Panchayat wise data corresponding to three districts of southern Kerala, were used to construct a soil fertility index for each panchayat followed by grouping of the panchayats in accordance with the index thus constructed. This objective was accomplished with the adoption of multivariate statistical techniques. The chapter contents are condensed under the following subsections:

3.1 Study area

3.2 Soil fertility parameters

3.3 Primary data analysis

3.4 Multivariate techniques

3.5 Kruskal-Wallis test

3.1 STUDY AREA

Pathanamthitta, Kollam and Thiruvananthapuram were the three districts selected from southern Kerala for the present study. Most of the soil fertility parameters show wide variation among the panchayats even within the same district and this variability in soil fertility status was assessed with the help of the index.

3.1.1 Kollam

Sample size of panchayats varied from 31 to 440. List of panchayats in Kollam district taken for the present study along with their sample size are presented in Table 1. Panchayats having more outliers were excluded from the analysis.

Table 1. Name of Panchayats in Kollam district and their sample size

Sl. No.	Name of Panchayat	Sample size	Sl. No.	Name of Panchayat	Sample size
1	Alappad	84	28	Panmana	102
2	Anchal	373	29	Pathanapuram	331
3	Aryankavu	48	30	Pattazhi	281
4	Chadayamangalam	236	31	Pattazhi Vadakkekara	270

5	Chavara	223	32	Pavithreswaram	269
6	Clappana	208	33	Perayam	155
7	Edamulakkal	359	34	Piravanthur	249
8	Elamadu	292	35	Pooyappally	233
9	Eroor	281	36	Poruvazhi	151
10	Ezhukone	263	37	Punalur MC	292
11	Ittiva	266	38	Sasthamcotta	194
12	Kadakkal	440	39	Sooranad North	245
13	Kareepra	149	40	Sooranad South	249
14	KarunagappallyM C	180	41	Thalavoor	322
15	Kottamkara	31	42	Thazhava	262
16	Kottarakkara	196	43	Thekkumbhagam	145
17	Kulakkada	308	44	Thenmala	291
18	Kulasekharapuram	155	45	Thevalakkara	80
19	Kulathuppuzha	440	46	Thodiyoor	201
20	Kummil	197	47	Thrikkadavur	247
21	Kunnathur	299	48	Ummannur	350
22	Melila	69	49	Veliyam	309
23	Mylam	327	50	Vettikkavala	338
24	Mynagapally	190	51	Vilakkudy	301
25	Neduvathur	335	52	West Kallada	177
26	Neendakara	69	Total sample size		12302
27	Oachira	240			

3.1.2 Pathanamthitta

57 panchayats of Pathanamthitta district were initially considered. Data from more than 50 soil samples were used for each panchayat. The names of the panchayats considered and their corresponding sample size are given in Table 2.

Table 2. Name of Panchayats in Pathanamthitta district and their sample size

Sl. No.	Name of Panchayat	Sample size	Sl. No.	Name of Panchayat	Sample size

1	Adoor MC	134	30	Mallappally	175
2	Anicadu	173	31	Mallappuzhassery	115
3	Aranmula	153	32	Mezhuveli	170
4	Aruvappulam	249	33	Mylapra	99
5	Ayiroor	227	34	Naranamoozhi	126
6	Chenneerkara	190	35	Naranganam	304
7	Cherukole	156	36	Nedumpram	25
8	Chittar	248	37	Niranam	96
9	Elanthoor	304	38	Omallur	91
10	Enadimangalam	246	39	Pallickal	224
11	Erathu	169	40	Pandalam	154
12	Eraviperoor	199	41	Pandalam Thekkekara	207
13	Ezhamkulam	255	42	Pathanamthitta MC	239
14	Ezhumattoor	214	43	Peringara	223
15	Kadampanadu	236	44	Pramadom	69
16	Kadapra	123	45	Puramattom	127
17	Kalanjoor	400	46	Ranni	111
18	Kallooppara	165	47	Ranni-Angadi	199
19	Kaviyoor	134	48	Ranni-Pazhavangadi	239
20	Kodumon	155	49	Ranni-Perunad	239
21	Koipram	224	50	Seethathodu	249
22	Konni	242	51	Thannithodu	205
23	Kottanadu	224	52	Thiruvalla MC	73
24	Kottangal	183	53	Thottapuzhassery	320
25	Kozhencherry	117	54	Thumpamon	138
26	Kulanada	95	55	Vadasserikkara	313
27	Kunnanthanam	101	56	Vallicode	183

28	Kuttoor	57	57	Vechuchira	233
29	Malayalappuzha	297	Total sample size		10616

3.1.3 Thiruvananthapuram

Soil fertility parameter data of 62 panchayats of Thiruvananthapuram were initially collected, which altogether constituted 10800 samples. List of panchayats in Thiruvananthapuram district considered for the study along with their sample size are presented in Table 3.

Table 3. Name of Panchayats in Thiruvananthapuram district and their sample size

Sl. No.	Name of Panchayat	Sample size	Sl. No.	Name of Panchayat	Sample size
1	Anad	235	33	Kuttichal	175
2	Andoorkkonam	119	34	Madavoor	148
3	Anjuthengu	24	35	Malayinkeezh	257
4	Aruvikkara	195	36	Manamboor	116
5	Aryancode	228	37	Mangalapuram	158
6	Athiyannoor	197	38	Manickal	267
7	Attingal MC	100	39	Maranalloor	217
8	Azhoor	105	40	Nagaroor	215
9	Balaramapuram	146	41	Nanniyode	258
10	Chemmaruthy	159	42	Navaikulam	260
11	Chenkal	177	43	Nellanad	162
12	Cherunniyoor	94	44	Ottasekharamanglam	238
13	Chirayinkeezhu	75	45	Ottoor	83
14	Edava	50	46	Pallickal	150
15	Elakamon	137	47	Panavoor	261
16	Kadakkavoor	87	48	Pangode	234
17	Kadinamkulam	111	49	Pazhayakunnummel	208
18	Kallara	251	50	Peringammala	373
19	Kallikkadu	110	51	Pulimath	279
20	Kalliyoor	217	52	Sreekariyam	188

21	Karakulam	213	53	Tholicode	456
22	Karavaram	191	54	Uzhamalackal	163
23	Karode	149	55	Vakkom	50
24	Karumkulam	213	56	Vamanapuram	145
25	Kattakada	128	57	Varkala MC	147
26	Kazhakkuttam	96	58	Vellarada	232
27	Kilimanoor	175	59	Vembayam	248
28	Kizhuvilam	34	60	Vettoor	267
29	Kollayil	165	61	Vilavoorkkal	88
30	Kudappanakunnu	89	62	Vithura	195
31	Kulathoor	74	Total sample size		10800
32	Kunnathukal	218			

3.2 SOIL FERTILITY PARAMETERS

The soil fertility parameters included in the study are pH, EC, OC, P, K, Ca, Mg, S, B, Cu, Fe and Mn.

3.2.1 Soil reaction (pH)

pH used to represent the measure of acidity or basicity of the soil. It is defined as the negative logarithm of activity of hydronium ions. pH scale varies between 0 and 14. Soils with pH< 7 are considered to be acidic and above are alkaline soils. Soils with pH equal to seven is said to be neutral soils. Majority of the Kerala soils (74%) are in the range of strongly acidic to slightly acidic.

3.2.2 Electrical conductivity (EC)

EC is the measure of soil salinity and it is varying in accordance with the moisture held by the soil. It is expressed in the units of deci Siemens per meter (dS m^{-1}).

3.2.3 Primary nutrients

Macronutrients N, P and K are together known as primary nutrients. Organic carbon content of soil is used as the indicator of soil nitrogen content. Organic carbon content is expressed in percentage. Phosphorous and potassium are expressed in kg ha^{-1}.

3.2.4 Secondary nutrients

Ca, Mg and S come under the category of secondary nutrients and are expressed in mg kg^{-1}. In general Kerala soils are deficient in available Ca and Mg, whereas Sulphur is adequate in many of the soils.

3.2.5 Micronutrients

Among the class of micronutrients, B, Cu, Fe and Mn are used to study the fertility status and are expressed in mg kg^{-1}. In soils micronutrients are found in soil surfaces, organic matters and in solid minerals. Kerala soils are generally deficient in micronutrients.

3.3 PRIMARY DATA ANALYSIS

Since the sample size is large, there is a high chance of having extreme values in the recorded observations. These extreme values are known as outliers. They can be of small values or high values. There are different methods to detect outliers. Present study used box plots to detect outliers in each parameter in each of the panchayats of these districts. Box plot is an excellent tool to detect the outliers in the data. It is a technique in exploratory data analysis to visually summarize the data. Box plot uses median, upper and lower quartiles and extreme data points to depict the similarity as well as spread of distribution of data (Williamson *et al.*, 1989). Data was cleaned by removing the outliers which can be identified as those points which are greater than or equal to three times of inter quartile range. This cleaned data was used for further analysis. From the cleaned data mean vectors for each panchayat encompassing the 12 soil fertility parameters were obtained. Mean and CV of each parameter were also estimated using the relations,

$Mean = \frac{\sum_{i=1}^{n} x_i}{n}$ where $x_1, x_2, \ldots x_n$ are used to denote the n values of a parameter

$$Variance = \frac{1}{n-1}\sum(x_i - \bar{x})^2$$

$$CV = \frac{SD}{\bar{x}}100$$

3.4 MULTIVARIATE TECHNIQUES

Since the data consists of many samples and variables, multivariate techniques can be used for further analysis. Methods like Principal Component Analysis (PCA), Factor Analysis (FA) were used here to construct the soil fertility status index of the panchayats. Intention behind the use of PCA in the present study was to reduce the dimension of the data and also to assign most reliable weights to the aggregating components so that a realistic index can be obtained for each panchayat. Factor analysis was adopted as a method to identify the most significant parameters of soil fertility, followed by elimination of the less significant ones from the analysis. This also nurtures dimension reduction.

3.4.1 Index

Index is nothing but a measure that is used to quantify a latent variable in terms of the indicator variables (Whitmore, 2012). Index can be of simple index or composite index. Simple index is constructed with a single indicator, whereas composite indices are an aggregation of multiple indicators. The present study makes use of the idea of composite index by giving unequal weights to the indicators. Soil Fertility Index (SFI) is the measure used in this study to quantify the soil fertility of different panchayats. The twelve soil fertility parameters will be expressed in terms of principal component scores and the index will be constructed as the weighted aggregation of these principal component scores. Principal component scores are estimated from PCA results.

3.4.2 Principal Component Analysis (PCA)

PCA is a multivariate technique mainly used for reducing the dimension of the large data set. The large number of dependent variables will be converted into comparatively lesser number of new components known as principal components (PCs) which are formed as the linear combination of the original variables. Each principal component will be orthogonal to all others (Abdi and Williams, 2010). The first principal component is the one which explains the maximum amount of variation in the data set. The second principal component is orthogonal to the first PC and accounts for next highest variation, but is not explained by the first PC. For better convenience, instead of taking all the variables in the original data, those principal components which encompass about 70-80 percent variation in the data or those PCs having eigen value more than one are considered for further analysis.

3.4.2.1 Derivation of principal components

Let $X^T = [X_1, X_2, \dots X_p]$ is p- dimensional vector with mean vector μ and variance covariance matrix $\sum$. Then $Y_1, Y_2, \dots Y_p$ represents the p linear combinations given by

.

$$Y_1 = a_{11}X_1 + a_{21}X_2 + \cdots + a_{p1}X_p = a_1^T X$$

3.1

$$Y_2 = a_{12}X_1 + a_{22}X_2 + \cdots + a_{p2}X_p = a_2^T X \quad 3.2$$

$$Y_p = a_{1p}X_1 + a_{2p}X_2 + \cdots + a_{pp}X_p = a_p^T X \quad 3.3$$

Thus the j^{th} principal component can be generalized as, $Y_j = a_j^T X$, a_j is coefficient vector of j^{th} principal component, which is orthonormalized.

Consider,

$$Var\ (Y_1) = E(Y_1 Y_1^T) = E(a_1^T X\ (\ a_1^T X)^T)$$
$$= E(a_1^T X\ X^T a_1)$$
$$= a_1^T \Sigma a_1 \quad 3.4$$

Since Y_1 is the first principal component, its variance ($a_1^T \Sigma a_1$) is maximum. This is a constrained optimization with objective of maximise $a_1^T \Sigma a_1$ subject to the constraint $a_1^T a_1 = 1$ (Chatfield and Collins, 1980).

This problem can be solved and values of a_1 can be obtained by Lagrangian method. In general, the Lagrangian function of $f_{(x)}$ subject to $g_{(x)} = c$ is given by

$$L_x = f_{(x)} - \lambda[g_{(x)} - c]$$

3.5

Where λ is known as Lagrangian multiplier

$$\text{i.e., } L_x = a_1^T \Sigma a_1 - \lambda[\ a_1^T a_1 - 1]$$

3.6

Taking the derivative with respect to a_1 and then equate to zero, we get

$$(\Sigma - \lambda I)a_1 = 0 \quad 3.7$$

i.e., a_1 is the eigenvector corresponds to λ_1 of Σ, λ_1 is the largest eigenvalue of the Σ.

λ is obtained from the characteristic function of Σ i.e.,

$$Det(\Sigma - \lambda I) = 0 \quad 3.8$$

$$Var\ (Y_1) = a_1^T \Sigma a_1$$
$$= a_1^T \lambda I a_1$$
$$= \lambda$$

Since the variance of Y_1 is maximum, λ should be the highest eigenvalue. Likewise, variance of the second principal component will be the next highest eigenvalue.

In general principal components can be represented as $Y = A^T X$, $A=[a_1, a_2, \ldots a_p]$.

$$\text{Var-cov matrix of Y, } \Lambda = A^T \Sigma A = \text{Dia}[\ \lambda_1, \lambda_2, \ldots \lambda_p]$$

$$\text{Tr}(\Lambda) = \sum_{i=1}^{p} \lambda_i$$

It is also found that, $Tr(\Lambda) = Tr(\sum) = Var(X)$

Hence, the proportion of variance explained by j^{th} principal component = $\frac{\lambda_j}{\sum_{i=1}^{p} \lambda_i}$

3.4.2.2 Scree plot

It is a graphical representation of eigenvalues of each principal component. When the eigenvalues become less than one, there will be a sharp change in the slop of the curve.

PCA can be performed with the help of various statistical softwares like SPSS, R etc. The number of principal components obtained will be the same as the dimension of the original data set. Principal components thus obtained are the eigenvectors associated with the eigenvalues of the variance covariance matrix (or correlation matrix) of the original data set and are actually represent the weights associated to each variable in the data. From all the PCs, the ones which are having eigen value more than one or which account for about 80 per cent variation in the data could be extracted. From the extracted PCs, principal component scores are obtained by multiplying the data matrix with the coefficient matrix of extracted PCs. Then the original variables can be replaced by principal component scores of extracted PCs. These principal component scores are used for the construction of indices.

3.4.2.3 Soil Fertility Index (SFI)

Let S_{ij} denote the j^{th} principal component score of i^{th} panchayat, $S_{ij} = X_i V_j$

Soil Fertility Index of i^{th} panchayath is estimated as :

$$SFI_i = \sum_j W_j S_{ij} \qquad 3.9$$

Where, $W_j = \frac{Var(PC_j)}{\sum_j Var(PC_j)}$

W_j is the weight of j^{th} principal component.

V= Coefficient matrix of extracted principal components.

X_i = Mean vector of soil fertility parameters of i^{th} panchayat

Using the above equation (3.9) SFI of panchayats are constructed. To have better convenience for interpretation and classification, the indices are normalized by the method of min-max normalization (Equation (3.10)) followed by classification of panchayats into different fertility classes of low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%).

$$\text{Normalized SFI} = \frac{Actual\ value - Min.value}{Max.value - Min.value} \qquad 3.10$$

3.4.3 Factor Analysis (FA)

It is a technique mainly used to identify the latent factors (common factors) that are responsible for the observed variation in the data set. Here each variable is expressed as the linear combination of common factors and additional sources of variation. Factor analysis also helps in dimensionality reduction of the data, where the variables having low factor loadings and low communality can be eliminated from further analysis.

Let $X^T = [X_1, X_2, \ldots X_p]$ is a p- dimensional vector with mean vector μ and variance covariance matrix ∑. Factor model corresponds to first variable and m common factors can be represented as, $X_1 - \mu_1 = l_{11} F_1 + l_{12} F_2 + \ldots + l_{pm} F_m + \varepsilon_1$

In general, factor model can be represented as $X = LF + \varepsilon$ 3.11

$$\Sigma = LL^T + \psi$$

3.12

L= Matrix of factor loadings F= Vector of common factors ε = Vector of specific variance

Likewise, all the p variables can be written as the linear combination of m common factors and specific variance. The coefficients represent the loading of variables on each factor. The factors as well as errors are independent of each other. Decision regarding the number factors to be retained is based on any of the following criteria.

1. Kaiser criteria (retain the factors with eigenvalues greater than one)
2. Factors which account for about 80% variation in the data.
3. By using scree pot.

3.4.3.1 Communality

The proportion of variance of i^{th} variable contributed by m common factors is known as the communality of i^{th} variable. It can be found as the sum squares of factor loadings of i^{th} variable on m factors.

Communality of i^{th} variable, $H^2 = \sum_{j=1}^{m} {l_{ij}}^2$ 3.13

3.4.3.2 Specific variance

The proportion of variance accounted for by additional sources of variation (specific factors) is known as specific variance.

3.4.3.3 Determination of factor loadings

An important step in factor analysis is to determine the factor loadings. It is actually the loadings of variables on each factor. There are different methods to estimate these factor loadings and are discussed in the coming section (Rencher, 1934).

3.4.3.3.1 Principal component method

In principal component method, specific variance will be neglected and sample variance covariance matrix (S) will be equated to factor loading part.

$$S = \hat{L}\widehat{L^T} \quad 3.14$$

Further S will be represented in its spectral decomposition form and equating it to the loading part. Thus L is estimated as

$$\hat{L} = CD^{1/2} \quad 3.15$$

C = Matrix of normalized eigenvectors of S , D = Diagonal matrix of eigenvalues of S

3.4.3.3.2 Principal factor method

This method uses an initial estimate of ψ and $\hat{L}\widehat{L^T}$ is equated to $S - \hat{\psi}$. Eigenvalues and eigenvectors of $S - \hat{\psi}$ are used to estimate L and it is obtained using the formula 3.15.

$$\hat{L} = CD^{1/2}$$

C = Matrix of normalized eigen vectors of $S - \hat{\psi}$, D = Diagonal matrix of eigenvalues of $S - \hat{\psi}$

3.4.3.3.3 Maximum Likelihood Method

L and ψ can be estimated by maximum likelihood method also, if these estimates satisfy certain relations which are given as

$S\hat{\psi}\hat{L} = \hat{L}(I + \widehat{L^T}\widehat{\psi^{-1}}\hat{L})$ and

$$\hat{\psi} = Dia(S - \hat{L}\widehat{L^T})$$

Among these three methods, the widely used method is principal component method.

3.5 KRUSKAL-WALLIS TEST

It is a non-parametric test equivalent to parametric test of one way ANOVA. It is used to check the significance of difference in mean values of more than two independent samples and sample size need not be same. The test statistic is given by, (Rangaswamy, 1995)

$$H = \frac{12}{N(N+1)} \sum \frac{{R_i}^2}{n_i} - 3(N+1) \qquad 3.15$$

n_i is the number of observations in i^{th} group.

r_{ij} rank of j^{th} observation from i^{th} group.

N is the total number of observations across all groups.

Calculated H will be compared with the critical value H_c to make a decision regarding the acceptance or rejection of the null hypothesis.

Results and Discussions

4. RESULTS AND DISCUSSIONS

In order to meet the objectives multivariate statistical methods were performed on the secondary data of 12 soil fertility parameters of Kollam, Pathanamthitta and Thiruvananthapuram districts of southern Kerala. Principal Component Analysis (PCA) and Factor Analysis (FA) were the multivariate techniques adopted. A soil fertility index corresponding to each panchayat of these districts was constructed and the panchayats were classified based on this index. The results of the study are given under the following subsections.

4.1 Primary data analysis

4.2 Descriptive statistics of the soil fertility parameters of Panchayats in Kollam

4.3 Soil Fertility Index and classification of Panchayats in Kollam

4.4 Descriptive statistics of the soil fertility parameters of Panchayats in Pathanamthitta

4.5 Soil Fertility Index and classification of Panchayats in Pathanamthitta

4.6 Descriptive statistics of the soil fertility parameters of Panchayats in Trivandrum

4.7 Soil Fertility Index and classification of Panchayats in Trivandrum

4.8 Comparison of panchayats in southern Kerala based on SFI

4.1 PRIMARY DATA ANALYSIS

Primary data analysis was meant to identify the outliers present in the samples collected. It was done by the construction of box plots. Box plots were drawn in the SPSS package and the outliers were removed from the data set of all the three districts. The panchayats with large numbers of outlier values were eliminated from the study in order to get a reliable classification result. As a result, the number of panchayats considered in Kollam district became reduced to 43 from 52. In the case of Pathanamthitta district the number panchayats considered for the analysis has come down to 50 from 57 and 44 from 62 in Thiruvananthapuram district.

4.2 DESCRIPTIVE STATISTICS OF SOIL FERTILITY PARAMETERS OF PANCHAYATS IN KOLLAM

After removing the outliers, mean vector, and CV of 12 soil fertility parameters corresponding to 43 panchayats of Kollam district was estimated and the results are presented in Table 4. It is evident from Table 4 that pH values in the 43 panchayats were considered to vary between 4.66 to 8.13 with mean value of 6.01 and CV of 10.99 per cent. Most of the panchayats in Kollam are having moderately acidic soil with a few panchayats belonging to the category of slightly acidic and strongly acidic soils. An estranged behavior is shown by Alappad and Panmana panchayats which are having slightly alkaline to moderately alkaline soils with their soil reactions are 7.56 and 8.13 respectively. EC ranged from 0.03 dS m^{-1} to 0.73 dS m^{-1} with mean value of 0.17 dS m^{-1} and CV of 72.03 per cent. CV of OC was 40.45 per cent with a mean value of 0.83 per cent in the range 0.46 to 2.06 per cent. Soils of only Elamadu and Vettikkavala panchayats possess high OC content. The remaining 41 panchayats are almost equally divided between the classes of low and medium OC content. Almost a similar CV (44.94 per cent) was noticed in P, having a mean value of 57.59 kg ha^{-1}. Kollam in general is considered to have high P content since 36 panchayats have positioned in the high class of P classification. In contrast to what has been observed in P, available K content is low in most of the panchayats of Kollam. Availability of K varied from 17.49 to 851.85 kg ha^{-1} with a CV of 92.31 per cent. Only three panchayats namely, Aryankavu, Mynagappally and Vettikkavala are having K content more than 275 kg ha^{-1}. It is decisive to say that Kollam is deficient in Ca availability with the evidence that 38 panchayats out of 43 are deficient in available Ca. Lowest amount of Ca was observed in Ittiva panchayat (2.03 mg kg^{-1}) and highest was in Aryankavu (529.23 mg kg^{-1}) with a CV of 74.15 per cent. CV of Mg was 77.63 per cent having lowest value of 3.57 mg kg^{-1} and highest value of 112.57 mg kg^{-1} and all the panchayats were deficient in Mg. Mean value of S was 9.41 mg kg^{-1}, showing a deficiency in most of the panchayats rather than adequacy with a CV of 189 percent.

Among the micronutrients considered highest consistency was shown by B and soils of almost all the panchayats were adequate in B content with a CV of 39.8 per cent. Its range of value was 0.13 to 1.17 mg kg^{-1}. Among all the nutrients, Cu showed highest CV (249.62 per cent) with a mean value of 3.65 mg kg^{-1}. Fe also exhibits high CV of 154.2 per cent. Mean value corresponds to Mn was 17.47 mg kg^{-1} with a CV of 63.59 per cent. From Table 4 it is possible to say that soils in all the panchayats of Kollam are adequate in Fe and Mn.

Table 4. Descriptive statistics including mean and CV of 12 soil fertility parameters of Kollam district

Panchayats\ Parameters	pH	EC (dS m^{-1})	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})	B (mgkg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn(mg kg^{-1})
Alappad	7.56	0.26	0.46	111.29	17.49	47.10	3.57	2.88	0.53	3.33	44.16	5.79
Anchal	6.09	0.73	0.85	19.01	150.56	109.15	48.90	13.30	0.31	5.66	69.68	30.18
Aryankavu	6.00	0.12	1.18	12.43	851.85	529.23	62.47	37.87	0.52	25.87	25.71	36.04
Chadayamangalam	5.48	0.11	0.55	65.03	179.96	104.20	10.43	2.58	0.86	0.71	21.53	24.99
Chavara	6.43	0.40	0.66	67.60	54.33	117.11	10.10	1.31	0.62	0.62	46.57	15.17
Clappana	6.59	0.14	0.73	76.00	114.54	144.76	7.49	1.28	0.16	0.51	39.21	20.07
Elamadu	5.96	0.43	1.95	11.72	209.67	274.91	53.10	58.10	0.17	0.96	14.62	20.59
Ezhukone	5.82	0.13	1.05	79.01	36.82	128.56	14.05	1.40	0.73	1.67	31.42	27.80
Ittiva	6.13	0.09	0.64	68.56	146.39	2.03	112.57	16.91	0.65	1.17	14.42	19.25
Kadakkal	5.75	0.25	0.71	56.94	195.91	96.82	12.71	2.76	0.82	1.10	14.20	15.18
Kareepra	7.23	0.14	0.97	65.45	31.77	97.58	65.62	0.88	1.17	2.32	20.01	5.25
Karunagapilly	4.66	0.21	0.63	65.22	81.59	62.41	35.67	3.21	0.89	0.60	10.40	10.18
Kottamkara	6.18	0.28	0.50	89.00	250.77	338.28	88.39	19.39	0.60	1.08	23.78	11.86
Kottarakkara	5.28	0.04	0.63	59.31	114.60	102.74	6.20	1.83	0.93	0.55	7.07	8.38
Kulakkada	5.43	0.13	0.60	57.93	180.25	207.25	48.60	1.71	0.73	0.59	19.52	26.93
Kulasekharapuram	5.82	0.12	0.74	65.05	194.77	99.47	7.28	5.83	0.85	0.58	58.24	9.01
Kummil	5.30	0.09	0.76	65.76	136.88	59.32	36.15	3.47	1.08	0.70	39.73	6.33
Kunnathoor	6.11	0.15	0.90	59.15	59.65	190.25	25.82	0.62	0.59	0.59	25.48	19.72
Melila	5.27	0.09	0.79	50.90	157.19	90.95	7.24	1.56	0.13	0.82	22.08	9.51
Mylam	5.37	0.23	0.97	42.98	32.08	82.16	5.95	1.93	0.83	0.69	20.15	18.29
Mynagapally	6.21	0.22	1.26	88.85	399.02	174.82	32.62	0.59	1.03	2.30	57.75	18.95
Neduvathur	5.78	0.11	1.50	9.67	136.03	485.88	56.38	33.10	0.14	1.32	11.38	14.24
Neendakara	6.82	0.21	0.86	32.54	64.09	121.74	12.19	0.99	0.22	0.34	9.40	2.33
Oachira	5.86	0.14	0.61	60.71	73.83	114.02	9.19	1.51	0.39	1.05	28.87	6.16
Panmana	8.13	0.15	0.67	91.69	24.84	61.28	48.64	3.17	0.78	1.89	53.37	14.76

Pavithreswaram	6.46	0.07	0.68	69.38	187.87	158.09	33.78	2.31	0.86	0.67	12.83	16.65
Perayam	5.80	0.03	0.90	29.00	72.00	46.90	5.10	0.19	0.83	2.30	14.00	10.80
Poruvazhi	5.31	0.12	0.82	72.46	197.66	149.03	34.16	4.20	0.82	0.80	54.65	39.05
Punalur	6.16	0.11	0.79	30.46	242.74	281.27	59.15	34.98	0.48	27.59	43.69	49.47
Sasthamcotta	5.17	0.08	0.63	81.98	189.58	130.78	59.35	1.68	0.65	1.09	23.10	28.66
Soornad North	5.34	0.42	0.74	65.37	59.93	203.32	23.93	2.14	0.68	1.65	18.33	8.04
Soornad South	6.24	0.15	0.89	67.35	57.53	121.64	23.64	0.67	0.48	0.59	18.20	20.98
Thazhava	6.26	0.15	0.59	69.44	132.76	182.97	55.73	1.56	0.64	1.02	37.95	19.33
Thekkumbhagam	6.85	0.11	0.70	33.26	174.78	65.79	9.03	1.49	0.54	0.86	27.88	5.55
Thenmala	6.01	0.11	0.92	17.85	129.05	349.37	55.94	17.17	0.26	6.56	46.12	24.94
Thevalakkara	5.79	0.13	0.58	78.10	73.03	77.45	12.00	2.59	0.66	2.20	41.29	8.46
Thodiyoor	5.70	0.11	0.62	99.02	27.10	138.98	14.15	0.85	0.72	1.24	42.07	3.52
Thrikkadavoor	6.84	0.18	0.80	68.50	91.71	75.26	10.90	1.51	0.72	0.65	21.03	19.67
Ummanoor	6.34	0.15	0.65	63.42	165.05	210.43	56.04	2.26	0.76	0.47	36.24	22.82
Veliyam	5.69	0.22	0.51	75.61	39.26	112.92	8.85	3.31	0.78	0.73	15.48	6.29
Vettikkavala	5.87	0.13	2.06	11.45	281.60	457.86	61.90	14.67	0.57	0.85	8.19	9.93
Vilakkudy	5.66	0.10	0.78	10.21	177.94	305.93	72.26	91.78	0.54	49.89	391.84	46.32
West Kallada	5.73	0.13	0.65	61.76	148.97	74.44	35.43	3.02	0.70	0.72	22.58	13.78
Over all mean	6.01	0.17	0.83	57.59	147.52	162.43	33.78	9.41	0.64	3.65	37.31	17.47
CV	10.99	72.03	40.45	44.94	92.32	74.16	77.63	188.98	39.78	249.62	154.22	63.59

4.3 SOIL FERTILITY INDEX AND CLASSIFICATION OF PANCHAYATS IN KOLLAM

The details on twelve soil fertility parameters of different panchayats in Kollam district was discussed in the previous sections. The purpose of the present study is to develop a single value unit free index which provides an overall indication of soil fertility status of each panchayat in Kollam district.

4.3.1 Principal Component Analysis Method

To develop the Soil Fertility Index (SFI), Principal Component Analysis (PCA) was used. PCA not only transforms the original indicators into their linear combinations known as principal components (PC), but also it provides an idea about the weight that is attributed by each indicator to the corresponding PCs. The numbers of principal components were selected either based on Kaiser- Meyer-Olkin criteria or those which accounts for about 80 per cent variation in the given data. In this work, PCA was performed using SPSS package and the results obtained are presented in Table 5

Table 5. Extracted principal components of soil fertility parameters in Kollam District

Variables	PC 1	PC 2	PC 3	PC 4
pH	-0.12	0.00	0.47	0.77
EC	0.05	-0.28	0.61	0.00
OC	0.50	-0.67	-0.06	-0.01
P	-0.72	0.38	-0.08	0.31
K	0.60	-0.16	-0.50	0.21
Ca	0.78	-0.37	-0.20	0.12
Mg	0.58	0.04	-0.18	0.51
S	0.90	0.15	0.18	-0.05
B	-0.40	0.42	-0.53	0.13
Cu	0.80	0.51	0.08	-0.04
Fe	0.56	0.66	0.30	-0.14
Mn	0.69	0.34	-0.09	0.01
Eigenvalues	4.50	1.84	1.33	1.04
Proportion of variance (per cent)	37.52	15.33	11.15	8.73
Cumulative variance (per cent)	37.52	52.85	64.00	72.73

In general, PCA extracts a number of PCs which is same as that of the original number of parameters, that is twelve numbers of PCs in this study. However, in this analysis, among them only the first four principal components extracted based on KMO criteria were used to construct the soil fertility index. The principal components were extracted from the correlation matrix of soil parameters of 43 Panchayats and these PCs are nothing but the eigenvectors associated to each eigenvalue of the correlation matrix. It is evident from the scree plot (Fig.1) that, there were only four eigenvalues greater than unity and the first four PCs accounted for nearly 73 per cent of total variation in the data (Table 5). The first principal component alone accounted for 37.52 per cent variation followed by 15.33, 11.15 and 8.3 percent variations respectively by the remaining three PCs. The coefficients corresponding to parameters of each principal component are taken as the weight associated with parameters, for the construction of SFI. The coefficients or weights of the components are provided in the coming section.

4.3.1.1 PC 1

It is evident from Table 5 that, the soil parameters S (0.90), Cu (0.80), Ca (0.78), P (-0.72) and Mn (0.69) had high loadings on the first PC as compared to other soil fertility indicators. Least coefficient was observed for EC (0.05). Loading of each fertility parameter on PC 1 is shown in Fig. 2.

4.3.1.2 PC 2

If we consider the second PC, highest loading was observed only for OC (-0.67) followed by Fe (0.66). pH has a coefficient/ loading of zero on PC2. The first and second PC altogether explained cumulative variation of 52.85 per cent. Fig. 3 represents the loading of each soil fertility parameters on PC 2

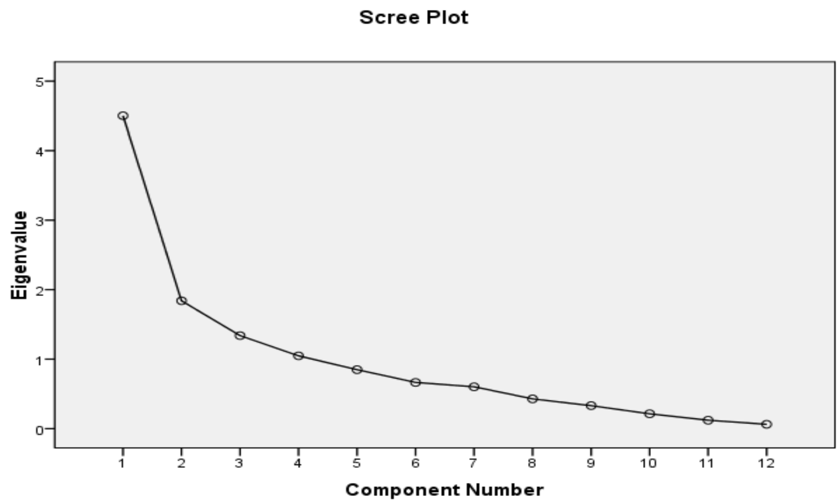


Fig. 1. Scree plot of PCA of Kollam

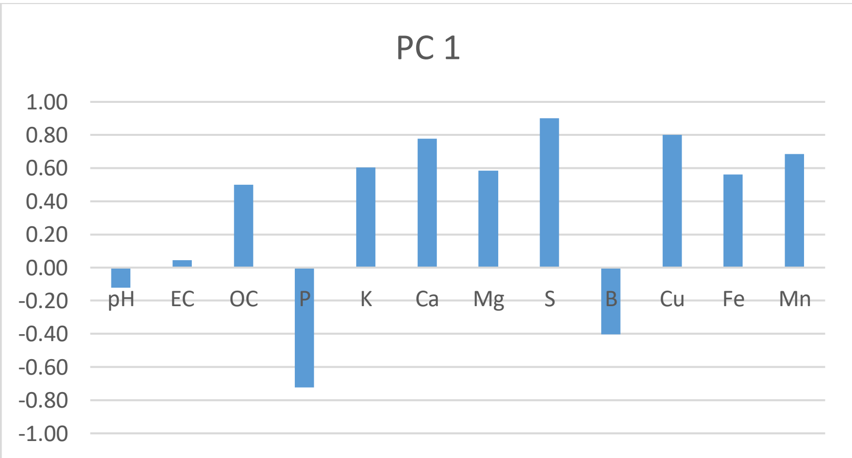


Fig. 2. Coefficients of soil fertility parameters on PC 1 in Kollam

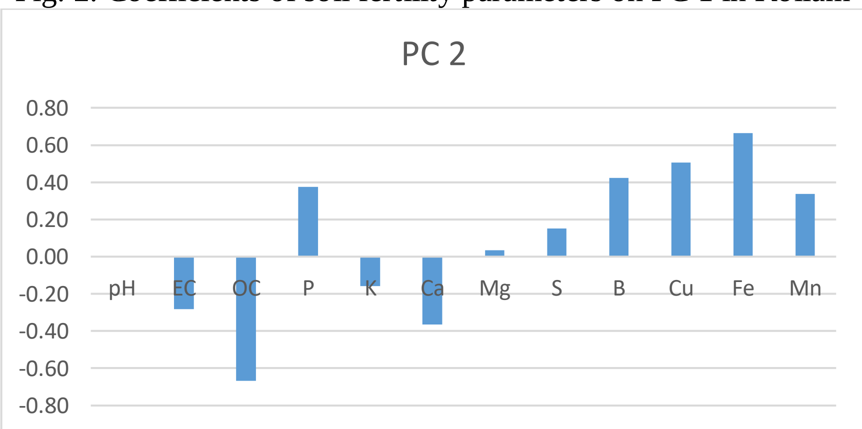


Fig. 3. Coefficients of soil fertility parameters on PC 2 in Kollam

4.3.1.3 PC 3

The third PC explained only 11.15 per cent of total variation with highest loading only for EC (0.61). Least coefficient was observed for OC (-0.06). (Fig.4).

4.3.1.4 PC 4

The results of PC 4 indicated that pH (0.77) had high loading on it. EC has no role in defining the PC 4 since it has a coefficient value nearly equal to zero. PC 4 accounted for 8.73 per cent variation in the data. Coefficient value of each soil fertility parameter on PC 4 is given in Fig.5 The soil parameters, Mg, B and K had relatively low loadings on all the four PCs (Table 5). Even though the weight/loading of the parameters B and Mg was less as compared to other indicators, it is also used in calculating PC score and SFI.

4.3.1.5 Principal Component Scores

Principal component scores for each panchayat was estimated by multiplying the mean vector of 12 soil fertility parameters of 43 panchayats with coefficient matrix generated using the first four PCs and it is presented in Table 6. These four score values itself was considered to be a single value SFI of all the panchayats. Instead of considering each PC score separately or the score based on the first PC, an index constructed by taking all together would be more meaningful because the first four PCs together accounted for nearly 73 percent variation of the data.

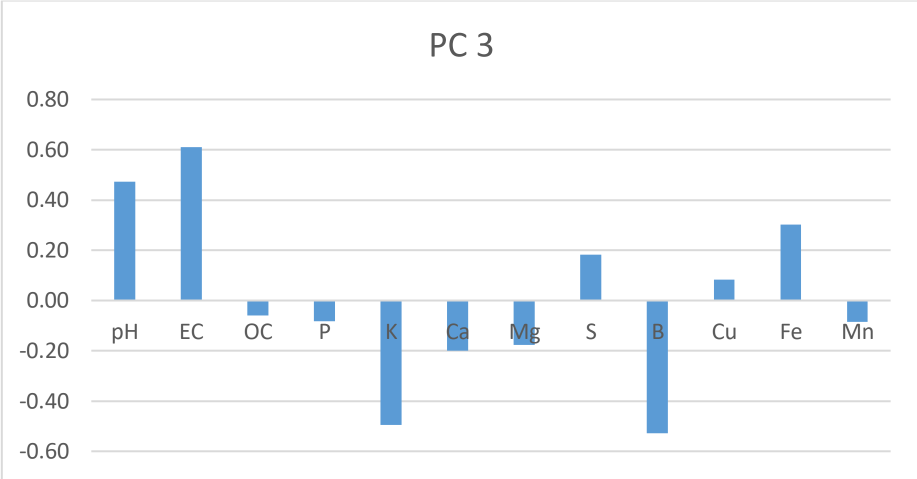


Fig.4. Coefficients of soil fertility parameters on PC 3 in Kollam

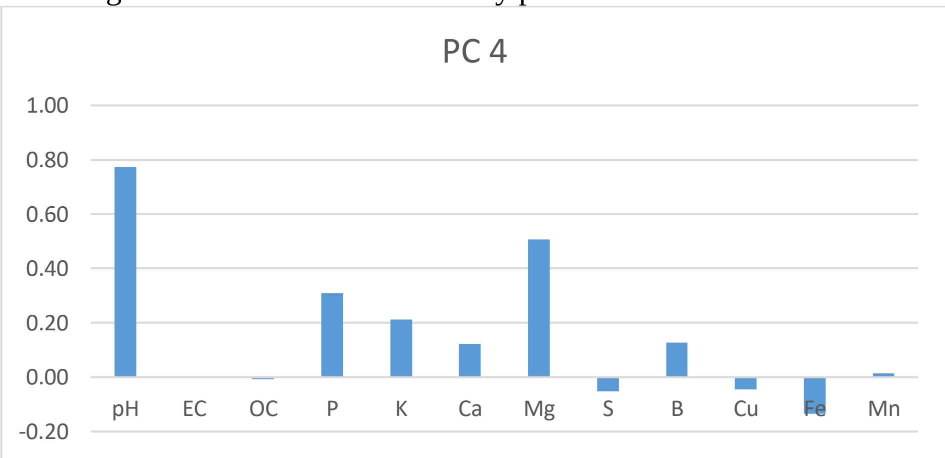


Fig.5. Coefficients of soil fertility parameters on PC 4 in Kollam

Table 6. PC scores of panchayats in Kollam district

Panchyats	PC 1 score	PC 2 score	PC 3 score	PC 4 score	Panchyat	PC 1 score	PC 2 score	PC 3 score	PC 4 score
Alappad	1.78	55.16	-10.72	45.32	Neendakara	124.24	-35.10	-54.73	48.74
Anchal	266.26	5.97	-81.94	70.74	Oachira	116.52	-8.44	-54.66	53.66
Aryankavu	1045.51	-273.37	-522.67	279.75	Panmana	68.07	51.57	-21.49	64.78
Chadayamangalam	179.81	-18.24	-109.91	77.87	Pavithreswaram	225.91	-45.42	-130.56	101.18
Chavara	118.18	10.67	-41.54	50.72	Perayam	78.51	-3.54	-42.45	35.27
Clappana	167.65	-9.34	-79.58	69.28	Poruvazhi	263.71	-6.92	-123.34	96.92
Elamadu	438.05	-102.58	-152.60	108.65	Punalur	488.72	-62.83	-168.69	121.93
Ezhukone	111.84	8.29	-42.86	55.62	Sasthamcotta	225.55	-19.14	-129.99	112.76
Ittiva	142.70	24.95	-89.84	111.57	Soornad North	179.09	-42.57	-71.94	71.62
Kadakkal	180.58	-29.14	-117.16	80.04	Soornad South	119.33	-8.22	-55.75	62.49
Kareepra	102.41	2.46	-43.28	75.05	Thazhava	240.38	-27.39	-104.77	100.16
Karunagapilly	86.82	1.11	-59.70	65.36	Thekkumbhagam	158.46	-18.04	-92.66	61.51
Kottamkara	439.98	-103.41	-201.77	167.66	Thenmala	432.06	-94.77	-126.52	101.74
Kottarakkara	120.64	-25.09	-79.34	61.57	Thevalakkara	87.05	21.56	-45.24	54.00
Kulakkada	286.76	-58.15	-137.58	108.03	Thodiyoor	87.91	12.38	-36.67	59.25
Kulasekharapuram	195.76	0.30	-102.56	73.78	Thrikkadavoor	96.98	5.03	-59.99	58.00
Kummil	131.72	12.02	-77.22	73.60	Ummanoor	287.30	-44.87	-126.54	109.03
Kunnathoor	184.22	-32.16	-67.99	68.88	Veliyam	77.58	-5.53	-42.49	52.26
Melila	153.45	-20.64	-92.72	64.96	Vettikkavala	578.36	-194.81	-235.55	153.70
Mylam	81.16	1.12	-29.68	34.80	Vilakkudy	753.71	181.28	-24.82	60.33
Mynagapally	378.28	-46.81	-226.75	147.21	West Kallada	148.34	-5.96	-91.22	79.14
Neduvathur	532.07	-176.11	-163.75	121.49					

The estimated scores of PC 1 and PC 4 were positive and they have shown a similar pattern. PC 1 score was very low in Alappad (1.78) and it was highest in Aryankavu panchayat (1045.51). However, PC scores of some of the Panchayat were negative based on PC 2 and PC 3 as is evident from the loading associated by the soil fertility parameters to these two PCs. 3D plot (Fig.6) of first three PC scores on 12 soil fertility parameters depicts the similarities and disparities between panchayats.

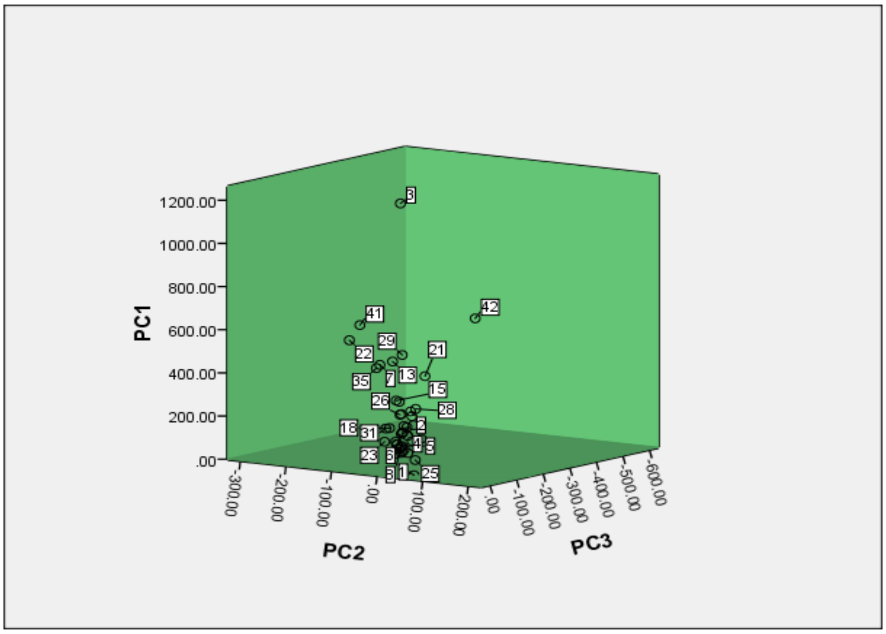


Fig.6. 3D plot of first three principal component scores in Kollam

Instead of assessing the fertility of panchayats based on these PC scores separately, an index of soil fertility can be constructed by aggregating the PC scores by providing weights to the PC scores. This method of index construction has been discussed in the coming section.

4.3.2 Soil fertility index

Let w_1, w_2, w_3 and w_4 are used to denote the weights associated to each PC score, denoted by S_1, S_2, S_3 and S_4. Then weight assigned to ith PC score is defined as,

$$w_i = \frac{VEPC_i}{\sum_{i=1}^{4} VEPC_i}$$

Where $VEPC_i$ represents variance explained by ith PC, i=1,2,3,4.

$$SFI = \sum_{i=1}^{4} w_i S_i$$.

Thus, the estimated weights of the first four PC scores S1, S2, S3, S4 are 0.52, 0.21,0.15 and 0.12 respectively. The Soil Fertility Index (SFI) of each panchayat is nothing but a weighted aggregation of PC scores. The index thus constructed is normalized by the method of min-max normalization using the equation,

$$\text{Normalized SFI} = \frac{Actual\ value - Min.value}{Max.value - Min.value}$$

The estimated SFI and normalized index are given in Table 7.

Table 7. Panchayat wise Soil Fertility Index constructed using PCA

Panchayats	SFI	SFI Normalized	Panchayats	SFI	SFI Normalized
Alappad	16.34	0.00	Neendakara	54.15	0.09
Anchal	134.53	0.28	Oachira	56.38	0.10
Aryankavu	435.12	1.00	Panmana	50.46	0.08
Chadayamangalam	81.40	0.16	Pavithreswaram	99.08	0.20
Chavara	62.93	0.11	Perayam	37.47	0.05
Clappana	80.62	0.15	Poruvazhi	127.29	0.26
Elamadu	193.98	0.42	Punalur	227.62	0.50
Ezhukone	59.54	0.10	Sasthamcotta	105.91	0.21
Ittiva	78.48	0.15	Soornad North	80.97	0.15
Kadakkal	78.65	0.15	Soornad South	58.77	0.10
Kareepra	55.72	0.09	Thazhava	114.18	0.23
Karunagapilly	43.71	0.07	Thekkumbhagam	71.11	0.13
Kottamkara	194.34	0.43	Thenmala	195.71	0.43
Kottarakkara	52.17	0.09	Thevalakkara	48.99	0.08
Kulakkada	127.53	0.27	Thodiyoor	49.45	0.08
Kulasekharapuram	94.17	0.19	Thrikkadavoor	48.85	0.08
Kummil	67.47	0.12	Ummanoor	132.43	0.28
Kunnathoor	86.09	0.17	Veliyam	38.61	0.05

Melila	68.39	0.12	Vettikkavala	239.60	0.53
Mylam	41.73	0.06	Vilakkudy	430.44	0.99
Mynagapally	168.16	0.36	West Kallada	70.77	0.13
Neduvathur	226.81	0.50			

The estimated SFI was ranged from a lowest value of 16.34 in Alappad to highest value of 435.12 (Aryankavu) with a CV of 82.45 per cent and the mean value was found to be 111.31. 29 panchayats out of 43 had SFI below the mean value indicating that more than 50 per cent of the panchayats are having a fertility status which is below the estimated mean value.

4.3.3 Factor analysis on soil fertility parameters

In the previous section soil fertility index was constructed by assigning weights to 12 soil parameters. However, all the soil property parameters are supposed to be not good indicators to measure the soil fertility of a particular location. Vasu *et al.* (2016) have adopted the concept of choosing the soil fertility parameters that had high loading for the construction SFI. This concept was replicated in this study by applying factor analysis to the data set and a selection or omission of soil fertility parameter was done based on factor loadings and communality. In this study, factor analysis was performed using the SPSS package by the method of principal axis factoring and rotation of factor loading by varimax rotation to reduce the dimension of the data. Based on Kaiser-Meyer-Olkin criteria only those factors which were having eigenvalue more than one were taken for further analysis. Those parameters which were having very low factor loadings (<0.5) on all the four factors considered were eliminated and PCA was performed again with a selected set of variables and the index is also constructed. The results of factor analysis are presented in Table 8.

Table 8. Results of factor analysis on 12 soil parameters in Kollam

Variables/Factors	1	2	3	4	Communality (Per cent)
pH	-0.102	0.037	-0.139	0.386	18.0
EC	0.035	-0.135	-0.286	0.178	13.3
OC	0.458	**-0.565**	-0.07	0.003	53.4
P	**-0.726**	0.396	0.29	0.347	88.8
K	**0.56**	-0.202	0.491	-0.028	59.6

Ca	**0.753**	-0.392	0.199	0.121	77.5
Mg	**0.519**	-0.012	0.238	0.282	40.6
S	**0.911**	0.149	-0.173	0.096	89.1
B	-0.359	0.288	0.404	-0.145	39.6
Cu	**0.821**	0.508	0.017	-0.078	93.8
Fe	0.566	**0.66**	-0.222	-0.018	80.6
Mn	**0.626**	0.235	0.167	-0.006	47.5
Variance Explained by the factors (%)	37.52	15.33	11.15	8.73	
Cumulative percent (%)	37.52	52.85	64.00	72.74	

The soil property parameters P, Ca, S and Cu had factor loadings more than 0.7 on Factor 1 with a communality of more than 75 percent and the parameters like K, Mg, and Mn had factor loading value between 0.5- 0.7 on Factor 1. The factor loading of OC and Fe were also in the range of 0.5 to 0.7 but it was based on Factor 2. All the other parameters like pH, EC and B were reported to had very low loading value (<0.5) on all the four factors and were having low communalities too. Hence the parameters pH, EC, Mg, B and Mn which were having communality below 50 per cent were eliminated from the analysis and PCA was repeated to the same data. The result of PCA is given in Table 9.

Table 9. Results of PCA on soil parameters

Variables	PC 1	PC 2
OC	0.55	-0.65
P	-0.76	0.28
K	0.61	-0.32
Ca	0.78	-0.39
S	0.90	0.25
Cu	0.80	0.52
Fe	0.57	0.76
Eigen values	3.65	1.66
Proportion of variance (%)	52.07	23.72
Cumulative variance (%)	52.07	75.79

It is evident from the Table 9 that the weights of most of the soil fertility parameters are relatively more in PC1 and the parameters like Fe and OC have high values on PC2 and these two PCs together accounted for nearly 76 per cent of total variation. Thus these two PCs were used further for the construction of SFI.

4.3.3.1 Principal component scores and SFI

As explained in section 4.3.1.5 PC scores were obtained by multiplying the mean vector of 43 panchayats with extracted principal component coefficients and it is presented in Table 10 and SFI was recalculated for all the panchayats and they are presented in Table 11.

Table 10. Principal component scores of modified data

Panchayats\ Parameters	PC 1 Score	PC 2 Score	Panchayats\ Parameters	PC 1 Score	PC 2 Score
Alappad	-5.82	43.10	Neendakara	116.77	-51.37
Anchal	219.66	-26.87	Oachira	107.40	-28.23
Aryankavu	994.07	-433.10	Panmana	29.08	35.89
Chadayamangalam	157.54	-62.83	Pavithreswaram	196.07	-91.64
Chavara	102.36	-8.14	Perayam	69.17	-21.83
Clappana	150.04	-41.47	Poruvazhi	218.44	-58.41
Elamadu	396.77	-145.49	Punalur	424.19	-122.41
Ezhukone	84.50	-14.82	Sasthamcotta	171.83	-70.27
Ittiva	63.71	-13.35	Soornad North	160.43	-64.40
Kadakkal	163.97	-72.80	Soornad South	91.34	-32.73
Kareepra	60.92	-13.44	Thazhava	195.88	-64.43
Karunagapilly	58.92	-23.37	Thekkumbhagam	151.18	-50.82
Kottamkara	382.56	-162.93	Thenmala	386.31	-129.17
Kottarakkara	111.89	-54.07	Thevalakkara	74.12	1.27
Kulakkada	241.77	-106.42	Thodiyoor	76.64	-2.09
Kulasekharapuram	186.77	-37.45	Thrikkadavoor	77.35	-23.12
Kummil	106.93	-17.65	Ummanoor	240.85	-88.54
Kunnathoor	156.68	-56.67	Veliyam	67.88	-22.25
Melila	143.59	-54.31	Vettikkavala	541.10	-254.83
Mylam	65.74	-14.43	Vilakkudy	687.65	171.70
Mynagapally	348.82	-126.61	West Kallada	118.89	-41.47
Neduvathur	494.27	-211.70			

It is evident from Table 10 that all the panchayats except Alappad had positive PC 1 score values whereas in the case of PC 2 scores, most of the panchayats have negative values. Similar to what was observed with 12 parameters, here also the highest PC 1 score is observed for Aryankavu panchayat (994.07) and Alappad possesses the lowest PC 1 score of -5.82. 2D plot of PC scores of panchayats is given in Fig.7. It is evident from the graph that there are only a few panchayats that had positive scores on both the PCs.

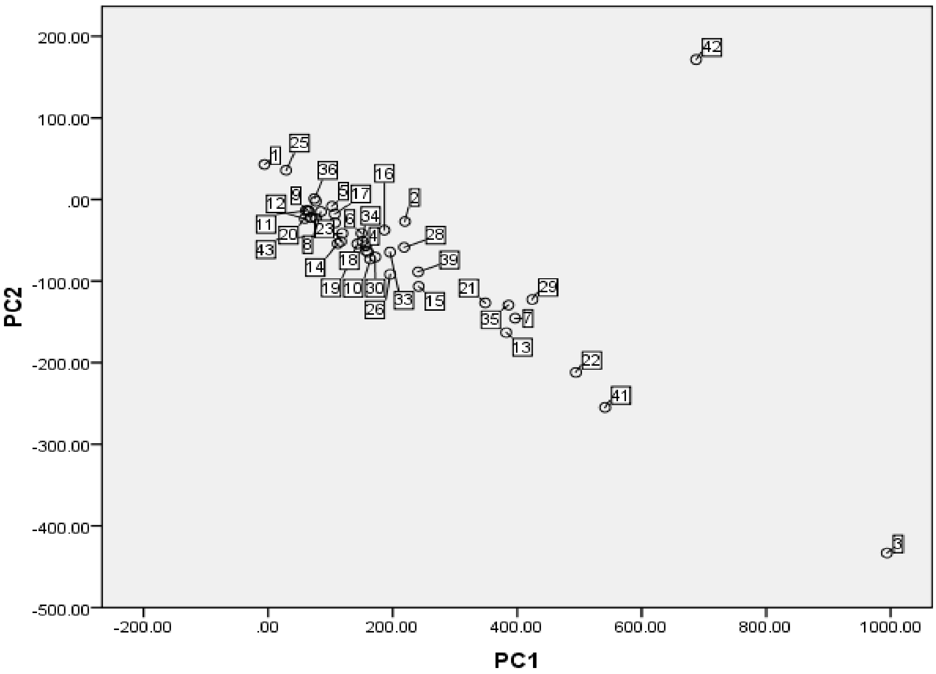


Fig.7. 2D of principal component scores after factor analysis in Kollam

Table 11. SFI- FA of 43 panchayats of Kollam district

Panchayats\ Parameters	SFI	Normalized SFI	Panchayats\ Parameters	SFI	Normalized SFI
Alappad	9.49	0.00	Neendakara	64.14	0.10
Anchal	142.50	0.25	Oachira	64.95	0.10
Aryankavu	547.41	1.00	Panmana	31.21	0.04
Chadayamangalam	88.57	0.15	Pavithreswaram	106.03	0.18
Chavara	67.77	0.11	Perayam	40.69	0.06
Clappana	90.10	0.15	Poruvazhi	131.79	0.23
Elamadu	227.06	0.40	Punalur	253.12	0.45
Ezhukone	53.42	0.08	Sasthamcotta	96.06	0.16
Ittiva	39.59	0.06	Soornad North	90.06	0.15
Kadakkal	89.87	0.15	Soornad South	52.51	0.08
Kareepra	37.65	0.05	Thazhava	114.41	0.20
Karunagapilly	33.17	0.04	Thekkumbhagam	87.96	0.15
Kottamkara	211.84	0.38	Thenmala	224.98	0.40
Kottarakkara	59.95	0.09	Thevalakkara	51.32	0.08
Kulakkada	132.80	0.23	Thodiyoor	52.00	0.08
Kulasekharapuram	116.60	0.20	Thrikkadavoor	45.90	0.07
Kummil	67.94	0.11	Ummanoor	137.76	0.24

Kunnathoor	89.91	0.15	Veliyam	39.67	0.06
Melila	81.66	0.13	Vettikkavala	292.00	0.53
Mylam	40.65	0.06	Vilakkudy	526.17	0.96
Mynagapally	200.02	0.35	West Kallada	68.70	0.11
Neduvathur	273.32	0.49			

The SFI- FA (SFI calculated after factor analysis) of some of the panchayats reported higher value for SFI as compared to index constructed based on all the 12 soil fertility parameters whereas a lower value is observed for remaining panchayats. It may be due to the predominance of some of the eliminated parameters in these panchayats. Alappad panchayat has a low fertility index (9.49) and Aryankavu panchayat possesses the highest (547.41) value (Table 11). SFI has shown a CV of 94.67 per cent as against 82.45 per cent in the earlier method. The observations are in concordance with that obtained from PCA performed without parameter elimination.

4.3.4 Classification of panchayats in Kollam

The panchayats in Kollam districts were classified in into four groups based on SFI and SFI- FA into low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%) as shown in Table 12 and Table 13 respectively.

Table 12. Classification of panchayats based on SFI

Groups (based on SFI) (%)	Name of the Panchayats	Number of panchayats
Low (0-25 %)	Alappad, Neendakara, Oachira, Panmana Chadayamangalam, Pavithreswaram, Chavara, Perayam, Clappana, Ezhukone, Sasthamcotta, Ittiva, Soornad North, Kadakkal, Soornad South, Kareepra, Thazhava, Karunagapilly, Thekkumbhagam, Kottarakkara, Thevalakkara, Thodiyoor, Kummil, Kulasekharapuram, Thrikkadavoor, Kunnathoor, Veliyam, Melila, Mylam, West Kallada	30 (69.77)
Medium (25-50 %)	Anchal , Poruvazhi, Elamadu, Punalur, Kottamkara, Thenmala, Kulakkada, Ummanoor, Mynagapally, Neduvathur	10(23.26)

High (50-75 %)	Vettikkavala	1(2.32)
Very high (75-100 %)	Vilakkudy, Aryankavu	2(4.65)

Note: values in the brackets are percentages

It is evident from Table 12 that 69.77 per cent of studied panchayats in Kollam district are having SFI value from 0-25 per cent (low), 23 per cent are in medium group and only three panchayats have high and very high fertility status. By making an analysis based on the index constructed with the mean values of various available nutrients, it was concluded that the parameters P, Ca, S and Cu are the major nutrients among the 12 nutrients which contribute more to the fertility status. It was observed that the panchayats Vettikkavala, Vilakkudy and Aryankavu possess medium to high status in the content of P, Ca, S and Cu and the panchayats belong to the category of medium fertility are observed to have medium to high content in some or more of these selected parameters. The remaining panchayats of low fertility are having less availability of these soil nutrients. No such discrimination was observed in any of the other parameters.

Table 13. Classification of panchayats based on SFI- FA

Groups (based on SFI) (%)	Panchayats	Number of panchayats
Low (0-25 %)	Alappad, Anchal, Neendakara, Oachira, Panmana Chadayamangalam, Pavithreswaram, Chavara, Perayam, Clappana, Ezhukone, Sasthamcotta, Ittiva, Soornad North, Kadakkal, Soornad South, Kareepra, Thazhava, Karunagapilly, Ummanoor, Thekkumbhagam, Poruvazhi, Kulakkada, Kottarakkara, Thevalakkara, Thodiyoor, Kummil, Kulasekharapuram, Thrikkadavoor, KunnathoorVeliyam, Melila, Mylam, West Kallada,	34 (79.07)

Medium (25-50 %)	Elamadu, Punalur, Kottamkara, Thenmala, Mynagapally, Neduvathur	6 (13.95)
High (50-75 %)	Vettikkavala	1 (2.32)
Very high (75-100 %)	Vilakkudy, Aryankavu	2 (4.65)

Note: values in the brackets are percentages

From the table of SFI- FA, it was clear that there are some disparities in some panchayats with respect to soil fertility status when we compare between SFI based on 12 parameters and the SFI- FA. Disparity is seen in Anchal, Poruvazhi, Kulakkada and Ummanoor panchayats, which were at medium fertility class with respect to initial SFI and categorized under low fertility status while considering SFI- FA. The reason for this disparity may be the elimination of parameters like B and Mn which were reported to be high at these panchayats.

4.4 DESCRIPTIVE STATISTICS OF SOIL FERTILITY PARAMETERS OF PANCHAYATS IN PATHANAMTHITTA

After the removal of outliers in the raw data, mean vector and CV of 12 soil fertility parameters corresponding to 50 panchayats of Pathanamthitta district were calculated and are shown in Table 14. pH value showed a variation from 4.20 to 6.56 with a CV of 8.92 per cent. It is possible to say that the soils of Pathanamthitta are mainly very strongly acidic to strongly acidic. A different behavior is shown by Kalloopra (4.2), Aranmula (6.47) and Kadapra (6.56) panchayats, which are having extremely acidic, slightly acidic and neutral soils. EC ranged from 0.06 dS m^{-1} to 2.75 dS m^{-1} with mean value of 0.33 dS m^{-1} and with a CV of 159.30 per cent indicated that high variation in EC across the panchayats. OC values varied from 0.64 to 3.26 per cent with a CV of 27.70 per cent showing a mean value of 1.65 per cent. All the panchayats except Kadapra are having medium to high OC content. A CV of 61.85 per cent was observed in P with a mean value of 66.62 kg ha^{-1}. 44 panchayats out of 50 included in the analysis were in a high class of P availability indicating that Pathanamthitta district is sufficient in P content. Availability of K varies between 148.32 to 475.67 kg ha^{-1} with a CV of 28.80 per cent and none of the panchayats are in low class of K content. It is decisive to say that calcium is sufficient in Pathanamthitta soils; even though a few panchayats recorded deficiency of Ca. CV of Ca is 48.60 per cent with a mean value of 634.92 mg kg^{-1}. In contrast to what was observed in Ca content, more than half of the panchayats considered here are deficient in Mg availability with a lower value of 26.62 mg kg^{-1} and a higher value of 461.50 mg kg^{-1}. All other panchayats except five panchayats are having S content more than 5 mg kg^{-1} with a mean value of 20.60 mg kg^{-1} and with a CV of 36.89 per cent. While considering the fertility status of micronutrients, B is having a CV of 102.39 per cent with its values in the range of 0.05 to 3.06 mg kg^{-1}. Most of the panchayats in Pathanamthitta are deficient in B. The conclusion thus arrived was in agreement with Venugopal *et al.* (2019). Cu and Fe are consistent with their CV 35.86 per cent and 41.56 per cent respectively. In the case of Cu, only Thottapuzhaserry panchayat had deficiency in Cu but all the panchayats had adequate Fe content. Pathanamthitta is completely sufficient in terms of Mn content showing a mean value of 28.80 mg kg^{-1} and a CV of 63.17 per cent.

Table 14. Mean values of 12 soil fertility parameters of Pathanamthitta district

Panchayat\ Parameter	pH	EC (dS m^{-1})	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})	B (mgkg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn(mg kg^{-1})
Adoor	4.75	0.12	1.30	28.77	323.26	199.20	36.40	25.00	0.61	1.31	36.64	18.07
Anicaud	5.16	0.32	2.10	74.28	358.60	676.90	62.90	25.00	0.78	2.52	47.86	39.26
Aranmula	6.47	0.40	1.51	118.03	389.35	1000.00	356.30	25.00	0.81	5.45	39.70	69.88
Aruvappulam	5.63	0.35	1.50	195.87	475.67	974.50	63.90	25.00	0.56	3.05	60.35	32.01
Ayiroor	5.17	0.22	1.87	68.16	310.22	929.50	357.30	21.30	0.60	5.51	24.17	55.07
Chenneerkara	5.29	0.15	1.32	100.17	295.03	685.80	127.00	22.50	0.74	2.58	38.92	47.78
Cherukole	5.51	0.13	1.84	95.72	322.93	587.50	67.70	21.50	0.53	3.39	48.19	39.96
Chittar	5.34	0.17	1.95	13.87	433.35	957.30	215.30	1.50	0.23	2.25	20.27	3.73
Enadimangalam	5.52	0.17	1.24	71.83	206.04	1000.00	49.10	21.10	1.06	3.50	31.52	30.53
Erathu	5.65	0.13	1.24	69.53	148.32	803.90	45.50	16.80	0.42	2.89	34.94	23.34
Eraviperoor	5.39	0.30	1.67	80.87	373.49	499.40	179.10	25.00	0.44	3.16	37.61	53.34
Ezhamkulam	5.30	0.14	1.13	68.34	174.14	161.10	30.10	25.00	1.25	4.89	40.41	25.38
Ezhumatoor	4.85	0.29	2.31	42.13	349.32	896.00	64.90	25.08	0.89	2.38	32.48	17.91
Kadampanadu	5.34	0.15	1.02	72.14	190.02	710.40	71.40	2.70	0.35	2.30	40.44	46.91
Kadapra	6.56	2.63	0.64	190.53	234.34	550.80	38.87	13.20	0.30	2.27	101.62	35.20
Kalanjoor	5.10	0.15	1.52	131.30	248.81	296.46	57.20	18.39	0.78	1.96	22.87	12.57
Kalloopra	4.20	0.25	2.63	19.60	284.35	469.23	310.00	25.00	0.33	1.93	20.80	11.02
Kaviyoor	5.17	0.14	1.77	108.79	325.33	534.40	62.60	23.30	0.31	2.01	36.51	36.47
Kodumon	5.31	0.06	1.61	80.06	154.34	171.10	34.70	17.80	0.99	2.10	40.94	15.67
Koipram	5.55	0.18	1.68	66.78	192.87	1000.00	59.30	19.80	0.67	2.50	61.81	61.37
Konni	5.09	0.18	1.83	39.03	310.48	920.60	455.90	25.00	0.16	4.06	33.21	38.55
Kottanadu	4.99	0.10	1.69	27.15	301.01	170.70	110.10	24.00	0.21	2.03	20.94	15.90
Kottangal	4.76	0.19	1.92	29.46	290.93	1000.00	52.80	2.00	0.86	1.94	34.73	54.57
Kozhenchery	5.07	0.09	1.54	83.09	262.74	718.30	49.90	21.60	0.70	3.49	28.58	13.72
Kulanada	5.45	0.27	1.42	69.53	250.45	890.40	261.20	1.30	0.52	1.48	21.52	21.06

Kunnanthanam	5.96	0.19	2.05	39.41	308.02	1000.00	71.70	25.00	0.49	3.47	41.89	23.33
Mallappally	5.77	0.18	2.18	68.52	368.96	932.20	138.90	19.80	0.55	2.44	28.55	74.49
Mallappuzhassery	5.19	0.12	1.35	41.32	184.28	538.90	47.80	17.00	2.15	2.08	42.19	54.34
Mezhuvelil	5.03	0.13	1.15	61.45	149.17	124.30	36.20	22.80	0.38	1.75	20.76	5.27
Mylapra	4.56	0.34	1.88	76.80	357.61	640.90	78.40	2.70	0.31	3.13	24.23	14.91
Naranamoozhi	4.73	0.57	3.26	29.13	289.49	967.60	266.60	24.30	0.34	3.78	30.25	16.10
Naranganam	5.45	0.10	1.31	93.92	275.83	82.10	40.50	22.90	3.06	2.51	33.15	21.26
Nedumbram	5.28	2.75	1.22	78.13	260.50	226.60	26.62	36.98	0.50	2.74	59.45	50.50
Omallur	5.73	0.15	1.52	134.45	236.08	612.60	83.10	17.10	2.84	2.15	43.36	44.37
Pallickal	5.29	0.17	1.46	77.90	216.45	867.40	76.30	25.00	0.54	2.05	49.99	37.14
Pandalam	4.52	0.16	1.62	17.91	225.04	208.00	83.20	23.20	0.13	3.58	32.33	11.71
PandalamThekkekkara	5.07	0.15	1.31	29.49	165.61	580.30	312.80	25.00	0.17	1.56	26.74	9.49
Pathanamthitta M C	5.08	0.29	1.32	73.82	349.02	826.30	78.30	25.00	0.36	3.87	36.60	27.13
Pramadom	4.65	0.32	2.09	103.97	307.93	869.50	76.10	23.00	0.37	3.32	48.39	23.40
Ranni	4.63	0.16	1.79	7.16	465.68	730.40	461.50	25.00	0.05	1.32	16.37	11.40
RanniAngadi	5.20	0.21	1.98	71.49	303.80	915.00	323.90	25.00	0.46	2.93	31.24	27.83
RanniPazhavangadi	4.70	0.23	2.15	63.17	262.03	805.00	403.40	25.00	0.20	3.04	22.83	10.53
Seethathodu	4.63	0.23	2.18	18.00	428.47	1000.00	456.20	25.00	0.19	2.46	24.61	17.94
Thannithodu	4.70	0.23	1.27	4.63	368.07	597.10	311.30	25.00	0.30	1.71	15.00	18.60
Thiruvalla M C	5.51	1.36	1.11	78.62	400.23	514.91	43.69	5.88	0.49	3.13	41.82	55.23
Thottapuzhaserry	4.75	0.08	2.16	25.85	156.71	112.30	29.90	15.60	3.00	0.87	24.65	7.77
Thumpamon	4.82	0.14	1.21	52.43	322.64	443.90	63.30	25.00	0.19	2.71	28.07	15.30
Vadaserrykkara	4.98	0.34	1.79	30.35	391.34	1000.00	273.70	25.00	0.29	3.43	23.42	10.72
Vallicode	5.51	0.20	1.25	84.85	258.54	186.50	54.80	25.00	0.31	2.30	30.45	26.74
Vechuchira	4.94	0.28	1.89	23.23	302.05	160.90	49.50	25.00	0.57	3.43	26.58	5.41
Mean	5.19	0.33	1.65	66.62	291.18	634.92	142.14	20.60	0.67	2.73	35.20	28.80
CV	8.92	159.30	27.70	61.85	28.80	48.60	94.30	36.89	102.39	35.86	41.56	63.17

4.5 SOIL FERTILITY INDEX AND CLASSIFICATION OF PANCHAYATS IN PATHANAMTHITTA

With respect to individual soil nutrients, an idea about the deficiency or adequacy of each nutrient is obtained. This section discusses the construction of SFI based on PCA to assess the overall fertility status of the soil. An index which indicates the fertility status of different panchayats of Pathanamthitta was constructed using the mean values of 12 soil fertility parameters mentioned in section 4.4.

4.5.1 Principal Component Analysis Method

As similar to the case of Kollam district, PCA was the method adopted to construct SFI of panchayats of Pathanamthitta district. In addition to dimension reduction, PCA also helps in assigning weights to the PC scores. The number of principal components was selected based on either Kaiser- Meyer-Olkin criteria or those which account for about 80 per cent variation of the data. Results of PCA performed using the SPSS package for Pathanamthitta districts are shown in Table 15.

Table 15. Results of PCA on soil fertility parameters in Pathanamthitta District

Variables	PC 1	PC 2	PC 3	PC 4
pH	0.80	0.26	-0.19	0.06
EC	0.56	0.17	0.52	-0.34
OC	-0.62	0.30	-0.13	0.21
P	0.79	0.15	-0.01	0.05
K	-0.26	0.65	0.09	-0.20
Ca	-0.10	0.79	-0.39	-0.12
Mg	-0.57	0.56	0.04	-0.03
S	-0.11	0.12	0.69	0.60
B	0.26	-0.48	-0.44	0.46
Cu	0.13	0.58	0.08	0.52
Fe	0.85	0.15	0.19	-0.07
Mn	0.57	0.44	-0.30	0.15
Eigen values	3.51	2.36	1.30	1.20
Proportion of variance (per cent)	29.22	19.63	10.75	9.10
Cumulative variance (per cent)	29.22	48.85	59.60	68.70

It is evident from the scree plot of PCA (Fig.8) that, among the 12 principal components the first four components are having eigenvalue more than one and are found to be more reliable for further analysis. First principal component explained 29.22 per cent variation in the data followed by 19.63, 10.75 and 9.10 per cent variations respectively by the next three principal components. The coefficients associated with the parameters on each PC represent the weights of the parameters on the corresponding PC which in turn emphasis the role of each parameter on PC. In accordance with KMO criteria, out of 12 PCs obtained from the correlation matrix based on 12 soil fertility parameters, the first four principal components which accounted for about 69 per cent variation were used to construct soil fertility index of 50 panchayats in Pathanamthitta district.

4.5.1.1 PC 1

It is evident from Table 15 that Fe has the highest coefficient (0.85) on PC 1 followed by pH (0.80). The parameters K, Ca, S, B and Cu are having coefficient values below 0.5 on PC 1. PC 1 accounted for 29.22 per cent variation in the data. Fig.9 represents the coefficients of soil fertility parameters on PC 1.

4.5.1.2 PC 2

While considering PC 2, only K, Ca, Mg and Cu are having coefficient values more than 0.5 on PC 2. Among that, the highest coefficient is observed for Ca (0.79). S is having the lowest coefficient value of 0.12. PC 2 along with PC 1 account for 48.85 per cent variation in the data. Fig.10 represents the coefficients of various parameters on PC 2.

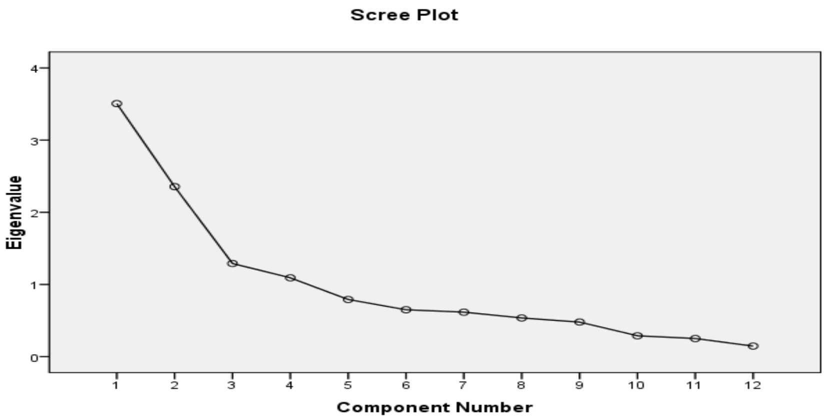


Fig.8. Scree plot of PCA on 12 soil fertility parameters in Pathanamthitta

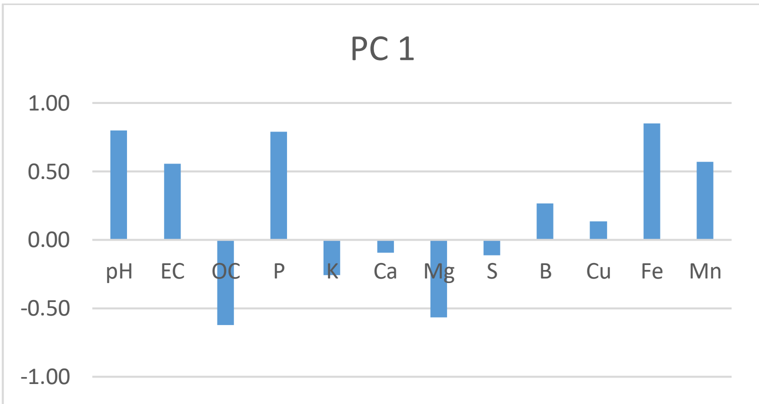


Fig.9. Coefficients of soil fertility Parameters on PC 1 in Pathanamthitta

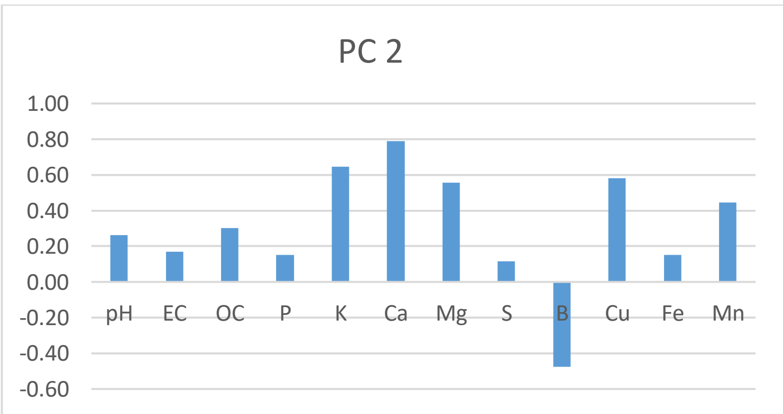


Fig.10. Coefficients of soil fertility parameters on PC 2 in Pathanamthitta

4.5.1.3 PC 3

PC 3 could explain 10.75 per cent variation in the data. Highest coefficient value was observed for S (0.69) followed by EC (0.52). Remaining 10 parameters are having low coefficient values of less than 0.5. Coefficients of parameters on PC 3 are as shown in Fig.11.

4.5.1.4 PC 4

In the case of PC 4, S (0.60) and Cu (0.52) are the parameters with highest coefficient value on PC 4 (Fig. 12). Among the remaining parameters which are having low coefficient value, the lowest is observed for Mg (-0.03). The individual contribution of PC 4 had an explanatory power of 9.10 per cent.

4.5.1.5 Principal Component Scores

Principal component score corresponds to 50 panchayats of Pathanamthitta district was obtained by multiplying the mean vector of panchayats with the coefficient matrix of the extracted principal components and it is presented in Table 16, so that each panchayat can be represented in terms of four PC scores instead of 12 soil fertility parameters.

While examining Table 16, it was clear that PC 2 score of all the 50 panchayats were positive even though there was one negative coefficient on PC 2 for B. None of the PC scores show any similarity in their values. In PC 3 score, except one value, all other values are negative and in PC 4 score, all values are negative. 3D plot (Fig. 13) of PC scores on 12 soil fertility parameters would also provide a visual grouping of panchayats underline the relevancy of classification of panchayats with low to high fertility status.

It is better to explain the soil fertility status of panchayats with positive value instead of using negative value, a single index constructed using these PC scores, which would provide a more reliable and valid classification. This index can be obtained by giving weights to the PC scores according to their proportion in explained variation. SFI constructed through weighted aggregation of PC scores are discussed in the following section.

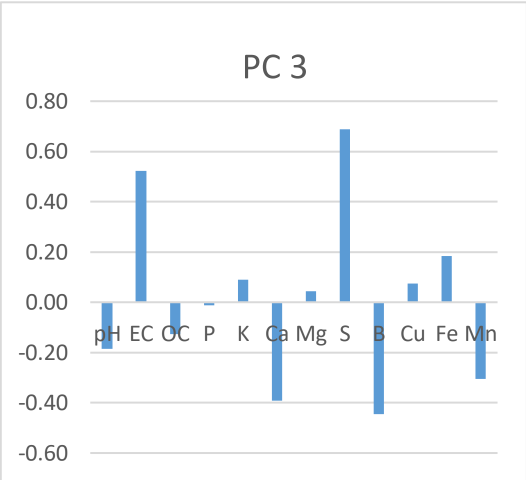


Fig.11. Coefficients of soil fertility parameters on PC 3 in Pathanamthitta

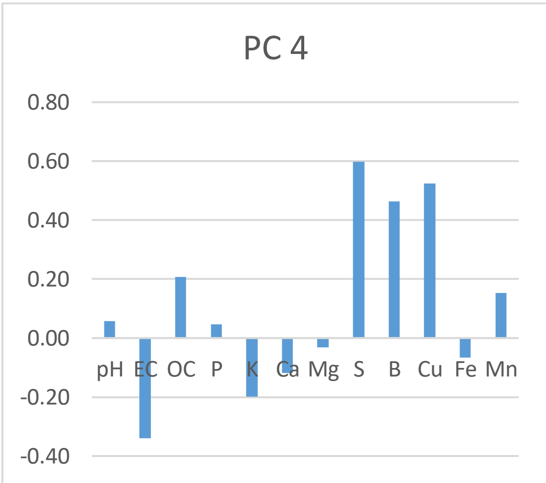


Fig.12. Coefficients of soil fertility parameters on PC 4 in Pathanamthitta

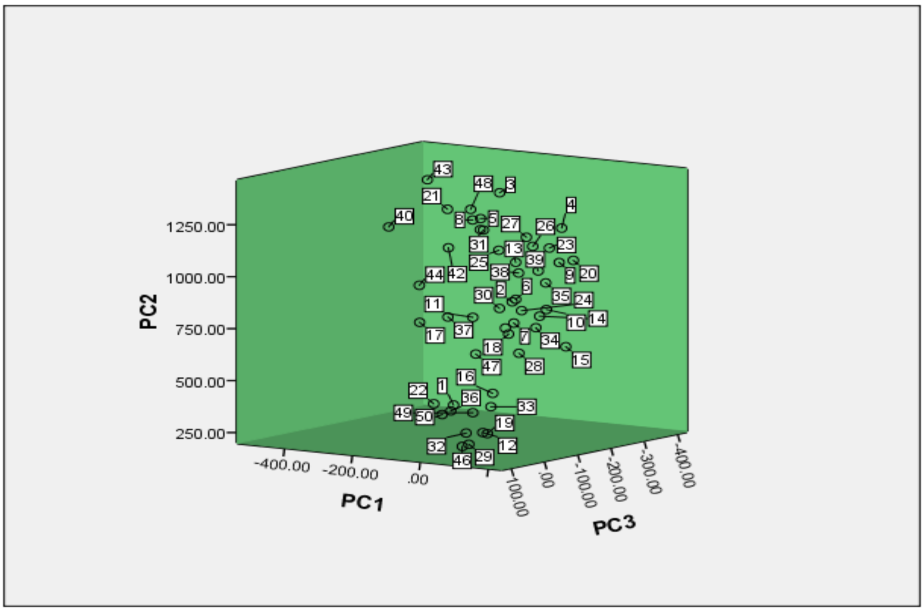


Fig.13. 3D plot of PC scores on 12 soil fertility parameters in Pathanamthitta

Table 16. PC scores of 50 panchayats of Pathanamthitta district

Panchayats	PC 1 Score	PC2 Score	PC 3 Score	PC 4 Score	Panchayats	PC 1 Score	PC 2 Score	PC 3 Score	PC 4 Score
Adoor	-57.96	409.21	-30.94	-70.90	Kunnanthanam	-134.18	1056.55	-346.30	-161.26
Anicaud	-70.06	842.12	-219.32	-129.69	Mallappally	-140.15	1103.68	-333.36	-161.11
Aranmula	-227.69	1300.26	-342.16	-174.60	Mallappuzhassery	-24.20	611.01	-192.68	-81.59
Aruvappulam	-25.73	1170.18	-322.49	-184.28	Mezhuvelil	-0.28	234.40	-17.82	-27.99
Ayiroor	-263.30	1177.11	-321.62	-156.36	Mylapra	-104.93	805.48	-216.52	-141.09
Chenneerkara	-72.24	849.44	-231.96	-118.63	Naranamoozhi	-260.04	1120.97	-326.81	-161.07
Cherukole	-36.58	755.04	-189.90	-112.83	Naranganam	15.20	298.65	6.12	-43.44
Chittar	-291.22	1164.38	-325.99	-203.37	Nedumbram	38.79	412.83	-44.21	-48.60
Enadimangalam	-73.49	983.46	-363.58	-139.18	Omallur	5.06	731.84	-213.63	-98.46
Erathu	-40.50	786.03	-291.72	-109.03	Pallickal	-55.61	907.28	-305.21	-125.04
Eraviperoor	-117.51	782.55	-149.28	-112.20	Pandalam	-75.89	374.84	-40.71	-55.15
Ezhamkulam	27.49	290.82	-31.56	-31.64	PandalamThekkekkara	-222.76	756.17	-181.92	-94.02
Ezhumatoor	-140.95	993.12	-302.16	-157.44	Pathanamthitta M C	-107.03	955.78	-276.23	-146.68
Kadampanadu	-35.26	763.29	-265.95	-112.63	Pramadom	-68.25	966.21	-295.40	-144.81
Kadapra	127.51	671.74	-178.74	-96.44	Ranni	-424.42	1147.02	-210.00	-176.39
Kalanjoor	7.48	459.77	-81.55	-66.82	RanniAngadi	-249.15	1131.50	-305.99	-155.93
Kalloopra	-254.41	742.55	-129.27	-103.84	RanniPazhavangadi	-296.93	1051.84	-259.06	-139.71
Kaviyoor	-31.45	709.98	-168.97	-105.81	Seethathodu	-418.45	1338.93	-320.07	-198.95
Kodumon	33.25	283.76	-39.28	-35.75	Thannithodu	-300.20	898.05	-175.17	-135.17
Koipram	-36.85	997.67	-368.88	-135.82	Thiruvalla M C	-43.27	735.81	-171.17	-127.01
Konni	-343.83	1214.40	-304.22	-161.74	Thottapuzhaserry	-20.45	220.31	-18.63	-32.76
Kottanadu	-106.98	410.37	-21.34	-65.14	Thumpamon	-86.44	618.59	-126.71	-98.74
Kottangal	-113.61	1042.19	-375.22	-166.98	Vadaserrykkara	-300.40	1212.60	-329.31	-185.70
Kozhenchery	-65.40	792.57	-242.84	-118.89	Vallicode	-5.68	379.78	-35.20	-52.36
Kulanada	-208.22	1034.31	-319.87	-155.91	Vechuchira	-76.27	366.11	-15.02	-62.93

4.5.2 Soil fertility index

SFI of Pathanamthitta was also constructed by the method adopted in 4.3.2. However, the weights associated with the four PC scores were different and it was estimated as 0.425, 0.286, 0.157 and 0.132 respectively. Table 17 given below represents the SFI of 50 panchayats using the scores and weights along with the normalized index obtained by the method of min-max normalization as mentioned in 4.3.2

Table 17. Panchayat wise Soil Fertility Index constructed using PCA

Panchayats	SFI	SFI Normalized	Panchayats	SFI	SFI Normalized
Adoor	78.02	0.15	Kunnanthanam	169.21	0.61
Anicaud	159.28	0.56	Mallappally	182.18	0.67
Aranmula	197.94	0.75	Mallappuzhassery	123.30	0.38
Aruvappulam	248.48	1.00	Mezhuvelil	60.35	0.07
Ayiroor	153.25	0.53	Mylapra	132.91	0.43
Chenneerkara	159.93	0.56	Naranamoozhi	137.16	0.45
Cherukole	155.48	0.54	Naranganam	86.99	0.20
Chittar	130.83	0.42	Nedumbram	121.08	0.37
Enadimangalam	174.36	0.63	Omallur	164.75	0.58
Erathu	147.23	0.50	Pallickal	171.21	0.62
Eraviperoor	135.36	0.44	Pandalam	61.13	0.07
Ezhamkulam	85.65	0.19	Pandalam Thekkekkara	80.35	0.17
Ezhumatoor	155.62	0.54	Pathanamthitta M C	164.87	0.59
Kadampanadu	146.52	0.49	Pramadom	181.59	0.67
Kadapra	205.39	0.79	Ranni	90.94	0.22
Kalanjoor	112.92	0.33	RanniAngadi	148.74	0.50
Kalloopra	69.94	0.11	RanniPazhavangadi	115.15	0.34
Kaviyoor	148.99	0.51	Seethathodu	128.09	0.40

Kodumon	84.32	0.19	Thannithodu	83.56	0.18
Koipram	193.62	0.73	Thiruvalla M C	148.19	0.50
Konni	131.66	0.42	Thottapuzhaserry	46.99	0.00
Kottanadu	59.77	0.06	Thumpamon	107.05	0.30
Kottangal	168.57	0.60	Vadaserrykkara	142.51	0.47
Kozhenchery	144.86	0.49	Vallicode	93.64	0.23
Kulanada	136.21	0.44	Vechuchira	61.47	0.07

SFI constructed by PCA showed a variation from 46.99 (Thottapuzhaserry panchayat) to 248.48 (Aruvappulam panchayat) with a CV of 33.49 percent and mean value of 131.75. More than half of the panchayats (28) were having SFI above the observed mean value, which roughly indicates the good soil fertility status of Pathanamthitta district.

In order to increase the efficiency of the classification, SFI was worked by eliminating some of the soil parameters that are not much relevant or have less variation among the panchayats instead of considering the 12 parameters. The result of the procedure adopted to reduce the dimension is explained in the next section.

4.5.3 Factor analysis of soil fertility parameters

With the intention to identify the most significant parameters of soil fertility, factor analysis was performed on the mean values of 12 soil fertility parameters of 50 panchayats in Pathanamthitta district. Factor analysis was done to exempt the parameters which were having low factor loadings (<0.5) on all the extracted factors followed by PCA on the modified data. This will help in further reduction of dimension of the data and to obtain an index which may provide more fruitful classification of panchayats. Factor analysis was performed using the SPSS package using principal axis factoring. Varimax rotation was adopted to obtain rotated factor loadings. Factors which were having eigenvalue more than one were considered for further analysis. Results of factor analysis are presented in Table 18.

Table 18. Results of factor analysis on 12 soil parameters of Pathanamthitta district

Variables/ Factor	1	2	3	4	Communality (Per cent)
pH	**.796**	-.153	.222	-.080	71.3
EC	.206	.033	**.765**	.054	63.4
OC	-.240	.424	-.346	.104	36.8
P	**.642**	-.218	.327	-.005	56.7
K	.023	**.576**	.009	.064	33.6
Ca	.408	**.751**	-.206	-.225	82.4
Mg	-.173	**.665**	-.208	.131	53.3
S	-.062	.063	.045	**.770**	60.3
B	.169	**-.530**	-.230	-.060	36.6
Cu	.381	.281	-.066	.296	31.6
Fe	**.614**	-.188	**.604**	.021	77.8
Mn	**.666**	.067	.077	-.043	45.6
Variance explained by the factors (Per cent)	29.22	19.63	10.75	9.10	
Cumulative variance (%)	29.22	48.85	59.60	68.70	

Based on Kaiser-Meyer-Olkin criteria, four factors extracted were having eigenvalue more than one and these were retained for further analysis. On examining the factor loadings, it was found that, the parameters like pH (0.796), P (0.642), Fe (0.614) and Mn (0.666) are having high loadings on factor 1 with a communality of 71.3, 56.7, 77.8 and 45.6 percent respectively. Whereas, K (0.576), Ca (0.751), Mg (0.665) and B (-0.530) possess high loadings on factor 2. EC (0.765) and S (0.770) had high loadings on factor 3 and factor 4 respectively. But OC and Cu didn't show a good loading value on any of the extracted factors and their communalities are also low. Hence it was decided to exclude OC and Cu from the analysis. Even though the parameters K, B and Mn had loading values of more than 0.5 on some factors, their communalities were respectively 33.6, 36.6 and 45.6 per cent respectively. The parameters that were having communality below 50 per cent were exempted from the construction of SFI. Thus PCA was repeated by eliminating these parameters and recalculated results of PCA are given in Table 19.

Table 19. Results of PCA on modified data

Variables	PC 1	PC 2	PC 3
pH	0.77	0.32	-0.08
EC	0.64	-0.03	0.39
P	0.83	0.11	-0.04
Ca	-0.04	0.93	-0.02
Mg	-0.54	0.61	0.41
S	-0.08	-0.23	0.88
Fe	0.90	0.05	0.15
Eigen value	2.81	1.40	1.12
Proportion of variance (%)	40.16	20.02	15.98
Cumulative variance (%)	40.16	60.17	76.16

By examining Table 19, it was found that the parameters pH, EC, P and Fe had high coefficients on PC 1 whereas Ca and Mg had high coefficient on PC2. S has shown high coefficient value on PC 3 rather than on other two PCs. These three PCs together accounted for about 76 percent of the total variation.

4.5.3.1 Principal component scores and SFI

As explained in the previous sections, here also PC scores were obtained by multiplying the mean vector of all the panchayats with coefficient matrix of extracted principal components and that are presented in Table 20. The SFI index along with standardized indexes is presented in Table 21.

Table 20. PC scores of modified data

Panchayats	PC 1 Score	PC 2 Score	PC 3 Score	Panchayats	PC 1 Score	PC 2 Score	PC 3 Score
Adoor	30.72	207.03	37.56	Kunnanthanam	-7.38	971.19	38.79
Anicaud	44.65	670.63	40.27	Mallappally	-28.37	953.36	59.91
Aranmula	-96.85	1154.32	152.61	Mallappuzhassery	26.69	531.82	29.77
Aruvappulam	143.95	960.12	32.61	Mezhuvelil	47.08	140.97	33.12
Ayiroor	-150.56	1084.19	150.67	Mylapra	19.91	651.01	24.12
Chenneerkara	23.34	721.18	61.88	Naranamoozhi	-130.56	1059.03	117.93
Cherukole	64.30	594.09	39.78	Naranganam	84.92	108.69	36.21
Chittar	-122.12	1021.41	75.89	Nedumbram	97.43	229.93	46.00
Enadimangalam	22.21	961.04	23.23	Omallur	83.21	631.74	39.56
Erathu	33.99	778.39	21.89	Pallickal	34.37	855.59	42.66
Eraviperoor	-14.04	578.09	89.33	Pandalam	-7.73	242.90	54.94
Ezhamkulam	72.31	172.46	34.56	PandalamThekkekkara	-142.07	728.99	143.43
Ezhumatoor	-6.40	870.31	36.42	Pathanamthitta M C	19.46	817.70	42.39
Kadampanadu	32.01	711.48	22.54	Pramadom	54.29	860.36	39.61
Kadapra	211.19	557.06	26.36	Ranni	-256.56	956.16	201.52
Kalanjoor	88.72	321.65	32.50	RanniAngadi	-123.13	1050.09	141.32
Kalloopra	-150.06	622.93	143.78	RanniPazhavangadi	-176.13	995.74	175.07
Kaviyoor	69.14	542.18	37.92	Seethathodu	-248.58	1203.80	195.58
Kodumon	80.12	187.46	29.55	Thannithodu	-173.39	740.33	141.82
Koipram	40.03	968.44	31.04	Thiruvalla M C	62.40	513.67	17.63
Konni	-219.57	1132.94	197.21	Thottapuzhaserry	25.34	123.98	26.42

Kottanadu	-23.01	225.35	65.22	Thumpamon	17.87	452.04	42.25
Kottangal	-11.00	963.14	10.25	Vadaserrykkara	-140.89	1093.11	119.74
Kozhenchery	39.84	701.77	27.90	Vallicode	62.82	212.48	42.16
Kulanada	-96.63	993.75	93.75	Vechuchira	11.84	178.66	42.37

It is clear from the above table that, PC 2 score and PC 3 score of all the 50 panchayats are positive. PC 2 scores are comparatively very high compared to corresponding PC 1 of all the panchayats. The 3D plot (Fig.14) of panchayats also provided an idea that the panchayats had high PC scores on three components. This 3D graph provided a more distinct classification of Panchayats as compared to the previous graph.

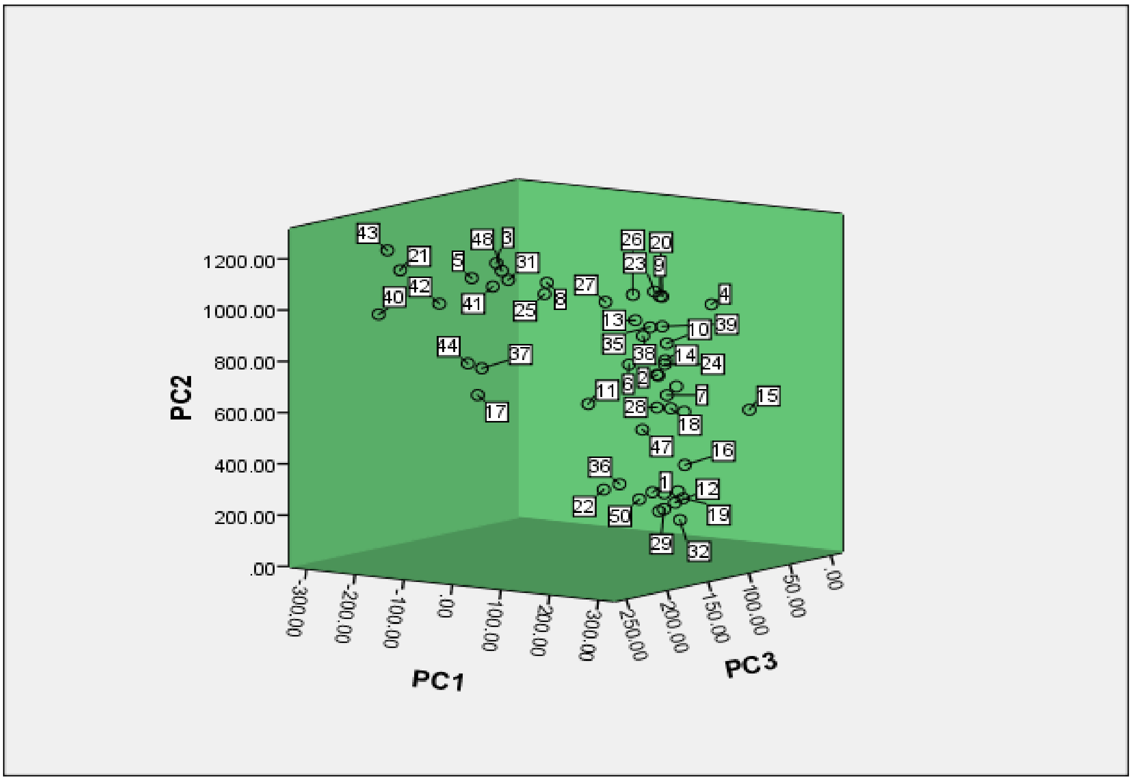


Fig. 14. 3D plot of PC scores on 7 soil fertility parameters in Pathanamthitta

Table 21. SFI- FA of panchayats of Pathanamthitta district

Panchayats	SFI	SFI Normalized	Panchayats	SFI	SFI Normalized
Adoor	78.50	0.10	Kunnanthanam	259.54	0.73
Anicaud	208.28	0.55	Mallappally	248.22	0.69
Aranmula	284.38	0.82	Mallappuzhassery	160.12	0.38
Aruvappulam	335.13	1.00	Mezhuvelil	68.83	0.06
Ayiroor	237.22	0.65	Mylapra	186.69	0.48

Chenneerkara	214.87	0.58	Naranamoozhi	234.29	0.64
Cherukole	198.42	0.52	Naranganam	80.94	0.10
Chittar	220.02	0.59	Nedumbram	121.47	0.25
Enadimangalam	269.21	0.77	Omallur	218.24	0.59
Erathu	227.13	0.62	Pallickal	251.98	0.71
Eraviperoor	163.30	0.39	Pandalam	71.30	0.07
Ezhamkulam	90.71	0.14	PandalamThekkekkara	146.81	0.34
Ezhumatoor	233.04	0.64	PathanamthittaM C	234.10	0.64
Kadampanadu	208.63	0.55	Pramadom	263.10	0.75
Kadapra	263.33	0.75	Ranni	158.34	0.38
Kalanjoor	138.15	0.31	RanniAngadi	240.76	0.67
Kalloopra	114.79	0.22	RanniPazhavangadi	205.60	0.54
Kaviyoor	186.94	0.48	Seethathodu	226.40	0.62
Kodumon	97.73	0.16	Thannithodu	132.94	0.29
Koipram	282.19	0.81	Thiruvalla M C	171.63	0.42
Konni	223.41	0.61	Thottapuzhaserry	51.50	0.00
Kottanadu	60.79	0.03	Thumpamon	137.12	0.30
Kottangal	249.53	0.70	Vadaserrykkara	238.17	0.66
Kozhenchery	211.33	0.56	Vallicode	97.83	0.16
Kulanada	229.94	0.63	Vechuchira	62.10	0.04

It is evident from the Table 21 that SFI varied from 51.50 to 335.13. Moreover, the index constructed based on the modified data has shown an increase in the value as compared to that constructed using all the 12 parameters. But the trends in SFI in both the case are on par with respect to the fertility status of the panchayats. Here also Aruvappulam is having highest SFI (335.13) and Thottappuzhaserry is with lowest SFI (51.50). As similar to what was observed in Kollam, here the SFI constructed using reduced data is having high CV of 38.30 per cent as compared to that with all the parameters (33.49). This is a clear indication of more disparity between the panchayats based on the SFI- FA.

4.5.4 Classification of panchayats in Pathanamthitta

Based on the normalized SFI constructed using all the parameters as well as a selected set of parameters, the panchayats of Pathanamthitta districts were grouped into four categories. i.e., low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (5-100%) and is presented in Table 22 and Table 23.

Table 22. Classification of panchayats based on SFI

Groups (based on SFI)	Panchayats	Number of panchayats
Low (0-25%)	Adoor, Ezhamkulam, Kalloopra, Kodumon, Kottanadu, Mezhuvelil, Naranganam,Pandalam,PandalamThekkekkara,Ranni, Thannithodu, Thottapuzhaserry, Vallicode, Vechuchira	15 (30)
Medium (25-50 %)	Chittar,Erathu,Eraviperoor, Kadampanadu, Kalanjoor, Konni, Kozhenchery, Kulanada, Mallappuzhassery, Mylapra, Naranamoozhi,Nedumbram, RanniAngadi, RanniPazhavangadi,Seethathodu, Thiruvalla M C,Thumpamon, Vadaserrykkara	18 (36)
High (50-75%)	Anicaud, Aranmula, Ayiroor, Chenneerkara,Cherukole, Enadimangalam, Ezhumatoor, Kaviyoor, Kottangal, Kunnanthanam, Mallappally, Omallur, Pallickal, Pathanamthitta M C, Pramadom	15 (30)
Very high (75-100%)	Aruvappulam, Kadapra, Koipram	3(6)

It is evident from Table 22 that, more panchayats of Pathanamthitta district (36 per cent) belong to medium fertility status followed by 30 per cent in both high and low groups. Only three panchayats namely, Aruvappulam, Kadapra and Koipram possess very high soil fertility. It was observed that the panchayats belonging to low fertility status have less availability of P and Ca compared to panchayats in other groups. So these nutrients may be considered as the most relevant parameters that contributed to soil fertility disparities among the panchayats in Pathanamthitta. It could also ascertain that fertility status of Pathanamthitta is good as compared to that of Kollam.

Table 23. Classification of panchayats based on SFI- FA

Groups (based on SFI)	Panchayats	Number of panchayats
Low (0-25%)	Adoor, Ezhamkulam, Kalloopra, Kodumon, Kottanadu, Mezhuvelil, Naranganam, Nedumbram, Pandalam, Thottapuzhaserry, Vallicode, Vechuchira	12(24)
Medium (25-50 %)	Eraviperoor, Kalanjoor, Kaviyoor, Mallappuzhassery, Mylapra, PandalamThekkekkara, Ranni, Thiruvalla M C, Thumpamon, Thannithodu	10 (20)
High (50-75 %)	Anicaud, Ayiroor, Chenneerkara, Cherukole, Chittar, Ezhumatoor, Erathu, Kadampanadu, Kadapra, Kottangal, Konni, Kozhenchery, Kulanada, Kunnanthanam, Mallappally, Naranamoozhi, Omallur, Pallickal, Pathanamthitta M C, Pramadom, RanniAngadi, RanniPazhavangadi, Seethathodu, Vadaserrykkara,	24(48)
Very high (75-100 %)	Aranmula, Aruvappulam, Enadimangalam, Koipram	4(8)

Classification based on SFI- FA, which was constructed using only the most significant parameters categorized 24 (48 per cent) panchayats of Pathanamthitta under high soil fertility class. In this classification the panchayat Enadimangalam was included under very high fertility class but was at high class in previous classification. It may be due to the elimination of K from the analysis which was comparatively low in Enadimangalam panchayat. Similarly, many panchayats which were at medium class previously got shifted to high class based on the SFI- FA. In contrast to what observed in Kollam wherein SFI- FA further degraded the fertility status of Kollam, the fertility status of Pathanamthitta has increased. Classification of panchayats based on recalculated PC score is more prominent than the 3D plot of the first one.

4.6 DESCRIPTIVE STATISTICS OF SOIL FERTILITY PARAMETERS OF PANCHAYATS IN THIRUVANANTHAPURAM

For studying the soil fertility status of panchayats of Thiruvananthapuram district, 44 panchayats out of the 62 were considered initially after removing the outlier values based on samples at the panchayat level. While proceeding with the mean vector of the 44 selected panchayats, it was found that the SFI constructed by PCA had negative values on eight panchayats and that was dissident from the results of other two districts which were considered earlier. When examining the values of fertility parameters of these panchayats and by constructing the box plots (Fig. 15) for the mean vector data, it was observed that there were extreme values in some of the Panchayats for the parameters like Cu, Fe and Mn. Hence, it was decided to exclude seven panchayats namely, Athiyannoor, Balaramapuram, Kalliyoor, Kilimanoor, Kuttichal, Madavoor and Malayankeezhu which were having extreme values for more than one parameter from the analysis and classified them in very low fertility class. Analysis and SFI construction were done on the remaining 37 panchayats followed by classification into various fertility groups. Study on the 37 panchayats and results are discussed in the coming sections.

Mean vector of Thiruvananthapuram district depicts mean values of 12 soil fertility parameters corresponding to 37 panchayats and it is presented in Table 24. It is evident from Table 24 that the pH value of 37 panchayats varied from 5.01 to 6.32 with a CV of 3.67 per cent. Thiruvananthapuram soils are slightly acidic in nature with a few exceptions where the soils are moderately to strongly acidic. Among the 12 soil fertility parameters EC showed the highest CV (152.15 per cent) with highest mean of 2.36 dS m^{-1} and lowest value of 0.04 dS m^{-1}. Mean value of OC content is 1.00 per cent with a CV of 37.58 per cent and most of the panchayats are having medium to high OC content. A CV of 28.17 per cent was observed in case of P with its mean in the interval 13.11 kg ha^{-1} and 38.94 kg ha^{-1}. All the panchayats have available P content above 11 kg ha^{-1}. But, here observed a deficiency of available K content in most of the panchayats of Thiruvananthapuram. Availability of K varied between 29.54 kg ha^{-1} to 550.05 kg ha^{-1} with a mean value of 177.01 kg ha^{-1}. CV of Ca was 34.94 per cent with a lowest value of 170.80 mg kg^{-1} and highest value of 882.50 mg kg^{-1}. Most of the panchayats are having available Ca content above 300 mg kg^{-1} which underscores the adequacy of

Ca in the soils of Thiruvananthapuram. In contrary to what has been observed in the case of Ca, only one panchayat Ottoor had adequacy in Mg availability. All the remaining 36 panchayats were deficient with respect to Mg status. Mg is having a mean value of 59.82 mg kg^{-1} and CV of 41.57 per cent. S content had shown a CV of 45.30 percent with highest value 61.38 mg kg^{-1} and lowest value 12.00 mg kg^{-1}. All the 37 panchayats were said to have an adequate amount of S in their soils.

B and Fe are having almost similar CVs of 54.24 per cent and 59.15 per cent respectively. Mean value of B is 0.30 mg kg^{-1} and that of Fe is 93.24 mg kg^{-1}. But deficiency of B and adequacy of Fe was observed in most of the panchayats. It is also evident from the Table 24 that Cu had a high CV of (130.98 per cent) which is an indication of high variation among the values. The lowest and highest observed Cu values were 0.08 mg kg^{-1} and 37.71 mg kg^{-1} respectively. Deficiency of Cu has been noticed only in two panchayats namely, Kallikkadu and Maranalloor. Among the micronutrients, Mn has shown consistency in the panchayats with a CV of 39.02 per cent with a mean of 36.90 mg kg^{-1}. Similar to what was observed in Kollam and Pathanamthitta districts all the panchayats, in Thiruvananthapuram also are having adequate amount of Mn in their soils.

4.7 SOIL FERTILITY INDEX AND CLASSIFICATION OF PANCHAYATS IN THIRUVANANTHAPURAM

Using the details on soil fertility parameters which are specified in the previous section, SFI corresponds to each panchayat of Thiruvananthapuram district was constructed. In order to construct the index, PCA was the method adopted and the index thus constructed could enable us to understand the soil fertility potential of panchayats separately. Method of index construction is explained in the following sections.

4.7.1 Principal Component Analysis Method

The features of PCA to convert the original variables into their linear combination followed by compression of data as well as its power to determine the weights to each of these new combinations have been made use in the present study. Similar to the previous situations, here also the PCs having eigenvalue more than one will be extracted from the PCA performed using correlation matrix of mean values of

37 panchayats. Results of PCA performed on the mean data of 12 soil fertility parameters of Thiruvananthapuram district with the help of SPSS software are shown in Table 25.

Out of the total 12 principal components, the first five PCs which were having an eigenvalue greater than one were selected for construction of SFI of Thiruvananthapuram district. These five PCs together accounted for 75.06 per cent variation in the data. The first PC explained 22.77 per cent variation of the data. The next four PCs explained 18.34, 14.26, 11.02 and 8.68 per cent variation of the data respectively. The coefficients of parameters on PCs also can be considered as weights associated with these parameters on different PCs. Fig.16 represents the scree plot of eigenvalues in PCA.

Table 24. Mean values of 12 soil fertility parameters of Thiruvananthapuram district

Panchayats	pH	EC (dS m^{-1})	OC (%)	P (kg ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})	B (mgkg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn(mg kg^{-1})
Anad	6.32	0.21	1.62	22.11	343.97	376.70	53.76	19.93	0.31	2.12	133.78	33.51
Andoorkonan	6.17	0.19	0.69	31.18	67.47	374.04	63.16	13.65	0.32	2.19	69.68	43.15
Aruvikkara	6.16	0.16	1.69	18.34	297.14	441.27	57.42	20.73	0.32	3.51	173.32	34.34
Attingal MC	6.18	0.20	0.51	23.16	97.99	408.29	48.34	14.49	0.30	5.91	125.78	49.04
Azhoor	6.17	0.14	1.64	20.00	377.56	498.91	52.41	20.16	0.13	1.80	125.10	39.14
Chenkal	6.07	0.14	1.30	15.68	450.25	355.76	53.89	20.74	0.32	7.94	69.71	43.29
Cherunniyoor	6.22	0.29	0.81	28.81	79.35	402.77	56.27	21.19	0.28	1.96	142.96	29.65
Chirayankeezhu	6.20	0.26	0.57	23.64	86.11	452.32	60.69	18.72	0.24	3.37	238.93	34.39
Edava	6.19	0.24	0.91	38.94	29.54	882.50	72.43	17.94	0.31	3.46	43.15	24.22
Elakamon	6.18	2.36	0.72	20.35	85.33	325.93	51.59	17.23	0.23	3.41	101.84	34.93
Kadakkavoor	6.13	0.19	0.78	17.91	59.05	252.64	52.20	19.00	0.26	2.87	132.27	47.73
Kadinamkulam	6.09	0.21	1.51	20.28	224.54	368.92	58.50	19.31	0.28	2.66	135.71	40.94
Kallara	6.13	0.22	0.89	20.98	94.09	420.48	54.82	18.34	0.25	3.07	28.91	18.86
Kallikkadu	6.23	0.10	1.70	34.72	61.91	490.09	50.21	30.69	0.08	0.08	1.17	1.08
Karavaram	6.21	0.15	0.76	18.52	120.35	297.38	60.03	17.06	0.26	4.65	79.54	56.24
Karode	6.05	0.12	0.60	20.01	135.23	374.59	56.99	19.28	0.28	5.33	74.23	53.64
Kazhakootam	6.22	0.25	0.72	32.50	82.34	452.09	67.03	21.13	0.28	5.76	127.85	58.27
Kudappanakunnu	6.18	0.17	0.59	14.33	82.62	301.55	70.69	18.55	0.25	3.05	42.17	23.06
Manamboor	6.14	0.17	1.57	22.90	550.05	356.39	56.10	16.93	0.32	4.30	78.05	55.33
Mangalapuram	6.31	0.23	0.67	37.64	67.11	348.29	60.31	12.36	0.28	3.27	65.59	46.44
Manickal	6.25	0.20	1.29	19.61	359.52	263.91	48.76	12.00	0.71	6.07	72.30	48.26
Maranalloor	5.76	0.08	0.89	30.30	68.38	200.13	58.74	33.15	0.11	0.43	24.36	1.49
Nagaroor	6.13	0.06	1.19	17.02	464.48	325.10	48.59	18.55	0.32	3.34	58.69	31.66
Nanniyod	6.18	0.24	0.84	20.21	70.56	540.82	57.94	22.04	0.25	3.49	61.53	32.58
Navayikulam	6.16	0.22	0.69	22.90	96.17	358.94	58.39	18.02	0.27	4.76	141.40	47.86

Nellanadu	6.18	0.23	0.81	23.44	96.35	332.15	52.08	22.60	0.25	3.21	157.03	37.20
Ottoor	6.08	0.22	0.60	17.98	162.30	334.80	200.79	13.13	0.21	1.99	99.86	37.98
Pallikkal	5.70	0.10	1.41	28.96	72.20	622.33	48.14	43.80	0.22	1.16	9.75	14.73
Panavoor	5.93	0.12	1.11	17.66	255.13	457.48	58.84	61.38	0.88	37.71	218.88	35.10
Pangode	6.16	0.22	1.36	17.62	123.19	255.52	52.26	16.55	0.24	2.34	78.28	54.32
Peringamala	6.31	0.10	0.90	17.07	141.99	203.70	55.01	12.38	0.83	12.78	162.29	47.18
Sreekaryam	5.01	0.20	1.10	21.09	216.64	170.80	29.60	25.00	0.14	1.60	15.83	11.39
Vakkom	6.18	0.25	0.63	20.92	88.80	393.33	54.45	20.81	0.24	2.44	82.56	40.08
Vamanapuram	6.16	0.04	0.48	13.11	194.73	583.60	58.50	14.52	0.35	4.50	65.60	40.85
Varkkala	6.10	0.18	1.25	20.41	154.40	224.24	54.98	12.76	0.37	3.10	71.88	48.06
Vembayam	6.16	0.19	0.85	22.05	86.68	526.02	59.78	17.90	0.32	5.61	50.99	23.46
Vettoor	6.28	0.21	1.22	32.11	505.98	312.60	59.54	13.66	0.26	5.11	88.81	45.75
Mean	6.12	0.24	1.00	22.82	177.01	386.12	59.82	20.42	0.30	4.60	93.24	36.90
CV	3.67	152.15	37.58	28.17	80.66	34.94	41.57	45.30	54.24	130.98	59.15	39.02

Table 25. Results of PCA on mean vector of Thiruvananthapuram district

Parameters	PC 1	PC 2	PC 3	PC 4	PC 5
pH	0.33	-0.59	0.14	0.56	0.14
EC	-0.06	-0.26	0.15	-0.31	0.70
OC	0.03	0.49	-0.62	0.42	0.12
P	-0.52	0.03	0.30	0.50	0.17
K	0.41	0.20	-0.72	0.25	-0.07
Ca	-0.24	0.16	0.49	0.63	-0.02
Mg	0.01	-0.36	0.24	-0.04	-0.68
S	0.05	0.87	0.35	-0.06	0.02
B	0.81	0.22	0.19	0.03	0.00
Cu	0.74	0.48	0.38	-0.05	-0.01
Fe	0.71	-0.11	0.26	0.05	0.13
Mn	0.64	-0.55	-0.13	0.11	0.03
Eigen value	2.73	2.20	1.71	1.32	1.04
Variance explained (%)	22.77	18.34	14.26	11.02	8.68
Cumulative variance (%)	22.77	41.11	55.37	66.39	75.06

4.7.1.1 PC 1

PC 1 alone accounted for 22.77 per cent variation in the data with High values are observed for B (0.81) followed by Cu (0.74). Lowest coefficient of 0.01 was observed for Mg. Coefficients of each soil fertility parameter on PC 1 is shown in Fig.17.

4.7.1.2 PC 2

When considering PC 2, highest coefficient was noticed for S (0.87) and lowest coefficient was for P (0.03) (Fig.18). Only pH, S and Mn were having a coefficient value above 0.5 on PC 2. PC 2 and PC 1 together explained for 41.11 per cent variation in the data.

4.7.1.3 PC 3

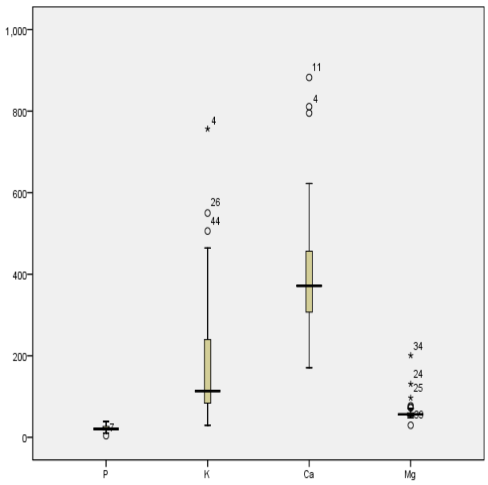
PC 3 was having an eigenvalue 1.71 and alone accounted for 14.26 per cent variation in the data. Based on PC 3, the highest coefficient value was noticed for K (-0.72). In PC 3, the lowest coefficient was observed for Mn for a value of -0.13. Parameter coefficients on PC 3 are as shown in Fig.19.

4.7.1.4 PC 4

Cumulative variance accounted up to PC 4 was 66.38 per cent. Here the highest coefficient was observed for Ca (0.63) and all the parameters except pH and Ca were having value below 0.5. B was having the lowest coefficient value of 0.03 (Fig. 20).

4.7.1.5 PC 5

While considering PC 5, EC had the highest coefficient of 0.70 and B had a coefficient value of zero on PC 5. PC 5 alone accounted for 8.68 per cent variation in the data. Coefficient value of each of the parameters on PC 5 are presented in Fig.21.



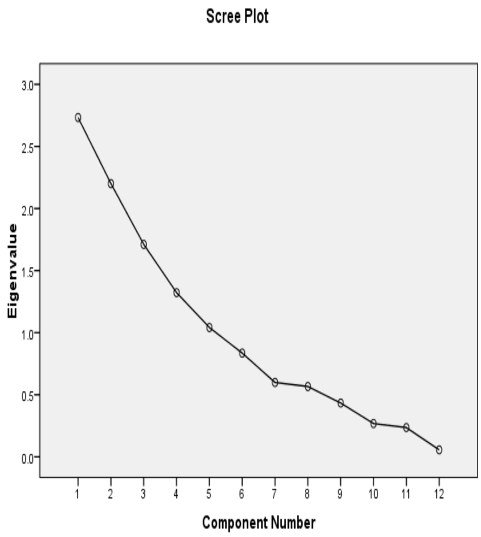
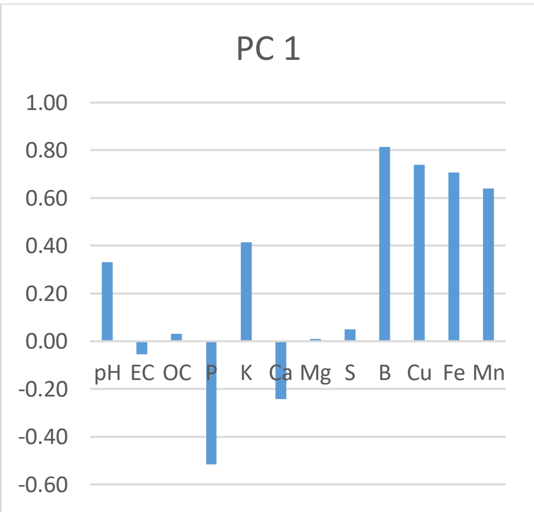


Fig. 15 Boxplot of panchayats for the parameters P, K, Ca, Mg

Fig.16. Scree plot of PCA in Thiruvananthapuram



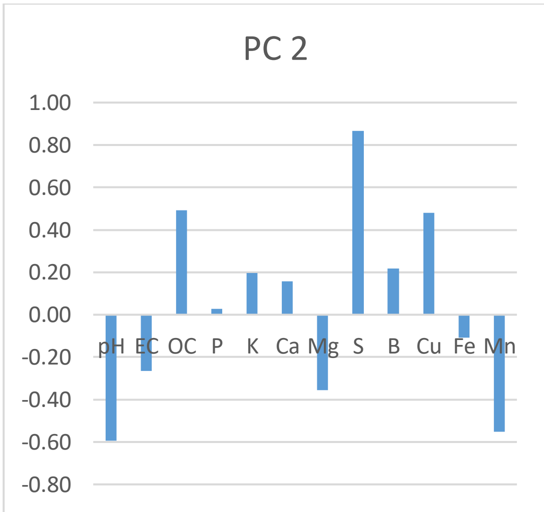


Fig.17. Coefficients of soil fertility parameters on PC 1 in TVPM

Fig.18. Coefficients of soil fertility parameters on PC 2 in TVPM

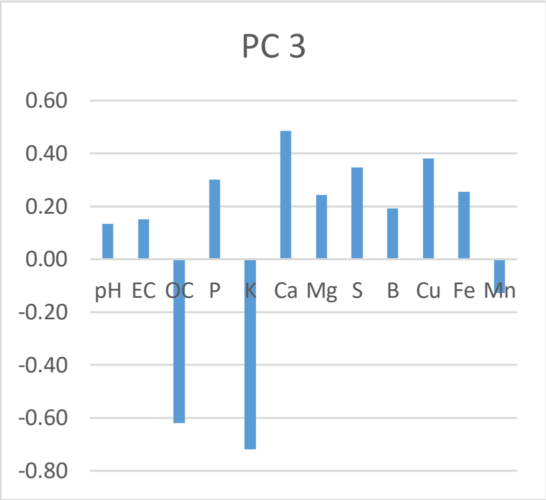


Fig.19. Coefficients of soil fertility parameters on PC 1 in TVPM

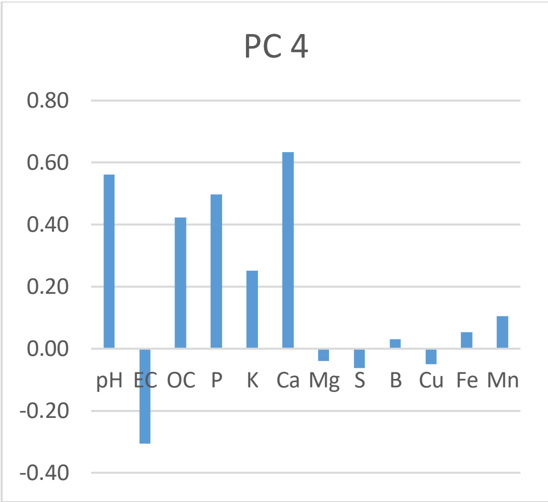


Fig.20. Coefficients of soil fertility parameters on PC 2 in TVPM

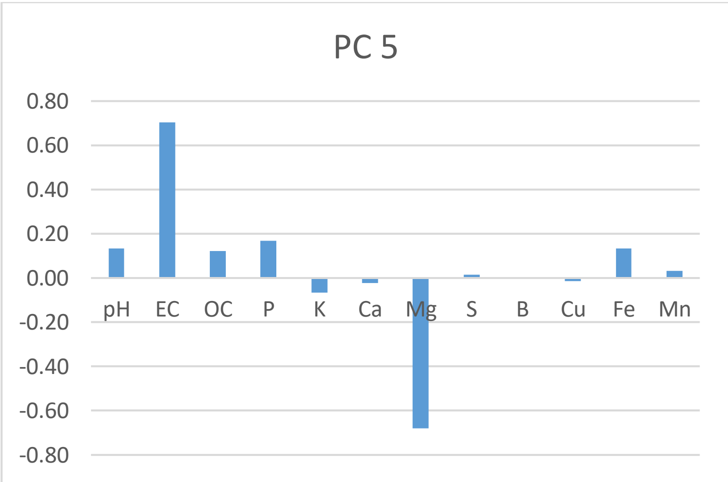


Fig.21. Coefficients of soil fertility parameters on PC 5 in TVPM

4.7.1.6 Principal Component Scores

Principal component scores of 37 panchayats of Thiruvananthapuram districts were estimated by multiplying the mean vector of the panchayats with the coefficient matrix of extracted principal components. Instead of 12 parameters, these five PC scores can be used to represent the fertility condition of each panchayat. Table 26 represents the PC scores of each panchayat.

From Table 26, it is clear that all the values of PC 4 scores are positive. The PC 2 score of the Ottoor panchayat is negative but it is positive for all other panchayats. Just opposite to PC 4 score, all the values of PC 5 scores are negative. For all the panchayats PC 4 scores are of large value compared to corresponding values of other component scores. If PC 1 score alone was considered as an index, then the highest index was observed for Manamboor panchayat (226.90) and lowest is for Andoorkonan (3.14). But it will give different results if other PCs are considered. So instead of determining the soil fertility status of panchayats using these individual PC scores, an aggregate index encompassing information from all these PCs will give a better estimate of the fertility condition of panchayats. While constructing such an index, each PC provided with weights corresponds to the proportion of variance explained by them.

Table 26. Principal component scores of 37 panchayats of Thiruvananthapuram district

Panchayats	PC 1 Score	PC 2 Score	PC 3 Score	PC 4 Score	PC 5 Score	Panchayats	PC 1 Score	PC 2 Score	PC 3 Score	PC 4 Score	PC 5 Score
Anad	161.09	90.96	-7.24	347.49	-43.95	Mangalapuram	5.85	24.01	163.86	264.96	-36.01
Andoorkonan	3.14	29.04	176.34	277.81	-39.24	Manickal	164.93	71.33	-93.82	277.38	-47.21
Aruvikkara	157.54	87.39	68.36	376.56	-40.34	Maranalloor	-13.23	47.49	89.39	159.67	-39.38
Attingal MC	57.72	38.63	180.40	307.04	-25.73	Nagaroor	172.52	116.52	-140.66	338.47	-58.14
Azhoor	143.41	115.22	23.94	432.39	-49.54	Nanniyod	-41.72	72.17	253.15	376.82	-42.99
Chenkal	178.65	113.22	-110.86	354.84	-59.92	Navayikulam	78.79	28.45	164.92	275.42	-29.16
Cherunniyoor	45.66	44.31	202.30	300.13	-26.88	Nellanadu	88.34	34.00	156.68	258.59	-22.28
Chirayankeezhu	110.97	37.28	244.81	336.01	-19.58	Ottoor	77.74	-8.90	126.61	265.92	-136.42
Edava	-169.79	116.56	452.82	589.97	-57.98	Pallikkal	-114.36	122.83	287.07	427.73	-44.09
Elakamon	46.09	32.93	145.29	246.82	-27.60	Panavoor	196.90	127.49	145.68	373.77	-32.96
Kadakkavoor	83.86	7.50	134.20	196.10	-22.01	Pangode	75.36	20.53	73.28	212.20	-33.25
Kadinamkulam	120.91	60.07	75.13	312.08	-39.10	Peringamala	158.96	11.22	60.40	187.14	-24.56
Kallara	-35.56	66.62	169.13	304.16	-44.21	Sreekaryam	60.31	71.50	-47.50	175.68	-31.00
Kallikkadu	-105.63	95.72	226.93	343.61	-42.34	Vakkom	20.12	45.64	171.44	290.49	-35.13
Karavaram	67.48	23.90	99.32	238.05	-39.11	Vamanapuram	11.58	91.75	180.51	433.04	-53.17
Karode	49.23	44.42	125.93	290.66	-40.44	Varkkala	86.38	22.05	35.33	200.69	-37.07
Kazhakootam	43.55	36.52	221.79	335.51	-36.17	Vembayam	-44.28	76.03	233.19	371.01	-46.44
Kudappanakunnu	4.25	36.00	124.54	223.11	-50.68	Vettoor	216.47	104.70	-164.50	351.44	-60.97
Manamboor	226.90	119.80	-181.95	386.18	-65.18						

4.7.2 Soil fertility index

SFI were obtained as the weighted aggregation of the five PC scores using the formula,

SFI $= \sum_{i=1}^{5} w_i S_i$, w_1, w_2, w_3, w_4 and w_5 are the weights associated to each PC score, denoted as S_1, S_2, S_3, S_4 and S_5 .

Weight of ith PC score, $w_i = \frac{VEPC_i}{\sum_{i=1}^{5} VEPC_i}$, VEPCi represents variance explained by ith PC, i=1,2,3,4,5. The weight is nothing but the ratio of the variance explained by each component to total variance explained by them and they were estimated as 0.30, 0.24, 0.19, 0.15 and 0.12 respectively. SFI estimated using the above mentioned method and its normalized values are presented in Table 27.

Table 27. SFI of 37 panchayats of Thiruvananthapuram district

Panchayats	SFI	SFI Normalized	Panchayats	SFI	SFI Normalized
Anad	115.64	0.57	Mangalapuram	73.49	0.24
Andoorkonan	77.77	0.27	Manickal	84.90	0.33
Aruvikkara	132.73	0.71	Maranalloor	43.45	0.00
Attingal MC	103.30	0.47	Nagaroor	97.05	0.42
Azhoor	133.94	0.72	Nanniyod	103.39	0.48
Chenkal	105.96	0.50	Navayikulam	99.23	0.44
Cherunniyoor	104.04	0.48	Nellanadu	100.24	0.45
Chirayankeezhu	136.32	0.74	Ottoor	68.72	0.20
Edava	142.85	0.79	Pallikkal	107.51	0.51
Elakamon	82.66	0.31	Panavoor	169.60	1.00
Kadakkavoor	79.00	0.28	Pangode	69.10	0.20
Kadinamkulam	106.91	0.50	Peringamala	87.07	0.35
Kallara	77.14	0.27	Sreekaryam	48.94	0.04
Kallikkadu	79.97	0.29	Vakkom	88.39	0.36
Karavaram	75.59	0.25	Vamanapuram	117.62	0.59
Karode	87.69	0.35	Varkkala	63.47	0.16
Kazhakootam	109.32	0.52	Vembayam	98.51	0.44
Kudappanakunnu	60.62	0.14	Vettoor	104.54	0.48
Manamboor	112.69	0.55			

SFI thus constructed has a mean of 95.93 and CV of 27.68 per cent with lowest SFI was obtained for Maranalloor (43.45) and highest was for Panavoor (169.60). 17 panchayats were having SFI below the mean value indicating that more than half of the panchayats are having fertility status above the observed average value. A 3D plot (Fig.22) of the principal component scores also depicts panchayats in different groups.

4.7.3 Factor analysis of soil fertility parameters

Just like it was done in the cases of Kollam and Pathanamthitta districts, factor analysis was performed in the case of Thiruvananthapuram also, in order to identify the most influential factors on soil fertility of panchayats. After extracting the factors based on Kaiser-Meyer-Olkin criteria, parameters were examined with reference to their factor loadings and communalities. The parameters with low loadings (below 0.5) and low communality were exempted from the mean data and PCA was performed on this modified data followed by recalculation of SFI. This will help to understand the significance of factor analysis in identifying the most important parameters. Results of factor analysis performed using the SPSS package on the mean vector data of Thiruvananthapuram district are presented in Table 28.

Table 28. Results of factor analysis on mean vector of Thiruvananthapuram

Parameter\ Factors	1	2	3	4	5	Communality (Per cent)
pH	0.14	**0.84**	-0.02	0.31	-0.01	81.4
EC	-0.05	0.13	-0.31	-0.09	**-0.75**	68.3
OC	-0.04	-0.15	**0.89**	0.09	-0.04	82.1
P	-0.28	-0.04	-0.05	**0.74**	-0.10	63.3
K	0.12	0.17	**0.81**	-0.29	0.13	79.6
Ca	0.07	-0.03	-0.04	**0.84**	0.13	72.1
Mg	-0.05	0.19	-0.41	-0.05	**0.66**	65.0
S	0.49	**-0.75**	0.09	0.25	-0.03	87.7
B	**0.84**	0.13	0.11	-0.13	0.05	74.7
Cu	**0.94**	-0.17	0.02	-0.03	0.04	92.3
Fe	**0.67**	0.37	-0.08	-0.08	-0.08	59.9
Mn	0.29	**0.76**	0.03	-0.29	0.02	74.4
Variance Explained by the factors (%)	22.77	18.34	14.26	11.02	8.68	
Cumulative(%)	22.77	41.11	55.37	66.39	75.06	

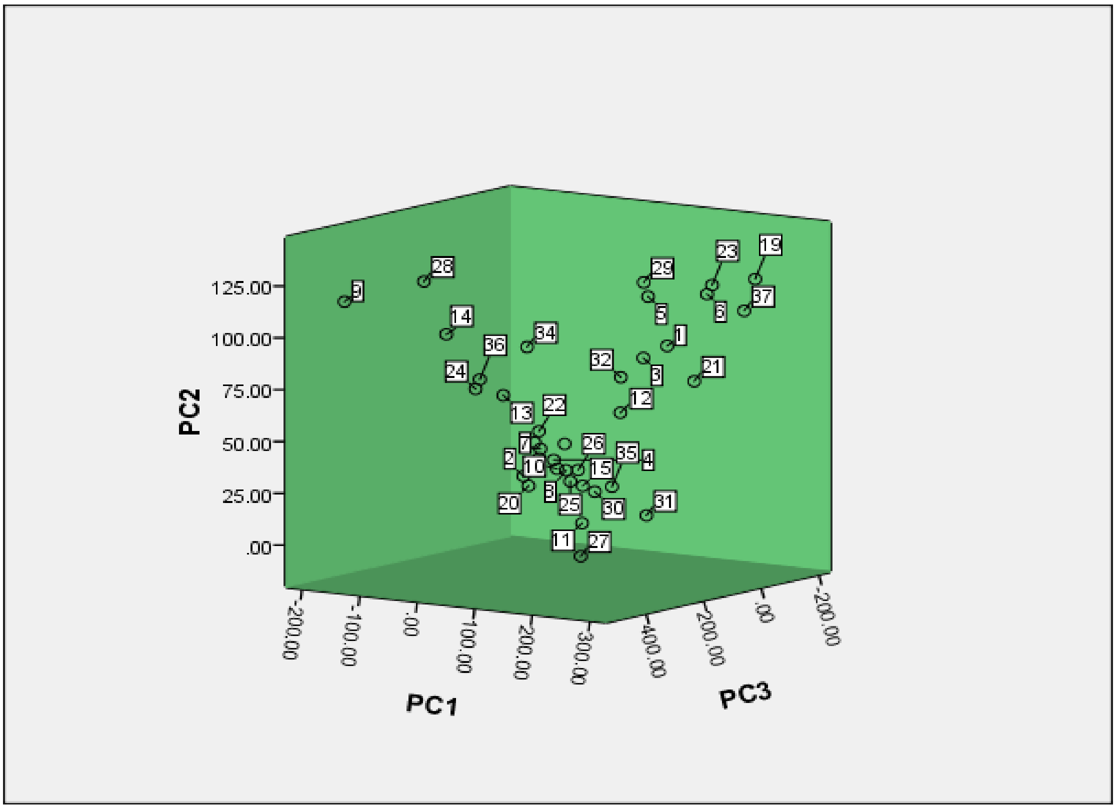


Fig.22. 3D plot of PC scores in Thiruvananthapuram

It is evident from Table 28 that five factors which were having eigenvalue more than one were extracted. The loadings of each parameter on the extracted factors are also given in Table 28. It is also clear that B (0.84), Cu (0.94) and Fe (0.67) were having high loadings (>0.5) on factor one with a communality of 74.7, 92.3 and 59.9 percent respectively. Whereas, pH (0.84), S (-0.75) and Mn (0.76) had high loadings on factor two. While considering third factor, high loading was observed for OC (0.89) and K (0.81). In the case of factor four, Ca (0.84) and P (0.74) showed a high loading value. Highest loading of Mg (0.66) and EC (-0.75) was on fifth factor. It was observed that all the 12 parameters possess high loading on one or other factors and all the parameters were having communality above 50 per cent. This indicates that all the parameters have their own role in explaining variation in the data. The results of factor analysis indicated that none of the parameters could be eliminated from the construction of SFI. Under this situation no further reduction in the dimension of data was required.

4.7.4 Classification of panchayats in Thiruvananthapuram

Classification of panchayats into four soil fertility classes namely low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%) will help to understand the overall soil fertility status of the district. This classification was done using the SFI constructed by the method mentioned above and it is presented in Table 29.

Table 29. Classification of panchayats based on SFI in Thiruvananthapuram

Groups (based on SFI)	Panchayats	Number of panchayats
Low (0-25 %)	Kudappanakunnu, Mangalapuram, Maranalloor, Pangode, Sreekaryam, Varkkala, Karavaram, Ottoor	8 (21.62)
Medium (25-50 %)	Andoorkonan, Attingal MC, Chenkal, Cherunniyoor, Kallara, Elakamon, Kadakavoor, Kadinamkulam, Kallikkadu, Karode, Manickal, Nagaroor, Peringamala, Vakkom, Nanniyod, Navayikulam, Vettoor, Nellanadu, Vembayam	19 (51.35)
High (50-75%)	Anad, Aruvikkara, Azhoor, Chirayankeezhu, Kazhakootam, Manamboor, Vamanapuram, Pallikkal	8 (21.62)
Very high (75-100%)	Edava, Panavoor	2 (5.4)

It is evident from the Table 29 that, more than half of the panchayats (51.35 per cent) of Thriruvananthapuram district considered in this study were having a medium soil fertility status. About 22 percent of the panchayats belongs to both low and high fertile classes. Only two panchayats namely Edava and Panavoor were observed to have very high fertility as compared to all other panchayats. In the case of Edava, the high fertility profile may be attributed to high content of Ca and Mg where as in Panavoor there observed a comparatively high content of K and S. In Thiruvananthapuram district about 79 percent of the panchayats were in the class of medium to very high group indicating that more pertinent soil fertility status for the panchayats in Thiruvananthapuram district included in the present study.

4.8 COMPARISON OF PANCHAYATS IN SOUTHERN KEREALA BASED ON SFI

After classifying the panchayats according to their soil fertility, an attempt was made to map this classification on the district map of the three districts considered in this study in order to visually understand the soil fertility status of the districts and it is given in Fig.23, Fig.24 and Fig.25 using GIS software. It was clear from the map itself that, most of the panchayats (red in colour) included in the present analysis of Kollam have shown a low soil fertility status with only two panchayats (green in colour) had very high soil fertility. But the map of the Pathanamthitta projects a different picture. It is obvious from the map of the Pathanamthitta that more than 50 percent (yellow and green coloured) panchayats come in the category of high to very high category. However, 24 per cent (Table. 23) of the panchayats was said to possess low soil fertility status. While considering Thiruvananthapuram, a distinct feature from other two districts was noticed. In this district seven panchayats out of 44 have shown negative SFI because of outliers for some of the parameters and these panchayats were put in the group of very low fertility. But many of the remaining panchayats possessed (51.35%) somewhat medium soil fertility status. Based on the panchayats included in the present analysis, it is decisive to say that Pathanamthitta district has good soil fertility status with a mean SFI of 185.90 as compared to Kollam (122.62) and Thiruvananthapuram (95.93). Kruskal-Wallis non-parameric test was applied to test the significance of constructed SFI of three districts. The results of Kruskal-Wallis test are given in Table 30. It is evident from Table 30 that the calculated Chi-square value (30.56) was greater than the critical value (5.991) of Chi-square with 2 degrees of freedom or estimated $p=0.0000, < 0.05$ indicated significant difference in SFI of three districts. The highest mean rank was obtained for Pathanamthitta (81.42) followed by Thiruvananthapuram (73.73) and Kollam (39.91) revealing that fertility status was more in Pathanamthitta as compared to other two districts.

Table 30. Results of Kruskal-Wallis test to compare mean SFI of the districts

Panchayats	Number of panchayats	Mean Rank	Estimated KW (χ^2)	Critical value (χ^2)	Estimated P value
Kollam	43	39.91	35.56	5.991	0.000
Pathananthitta	50	81.41			
Thirivananthapuram	37	73.73			

FUTURE LINE OF WORK

- In the present study, SFI was constructed for only three southern districts and the comparison between the districts was meaningful if we consider individual indicators. So this can be further extended to remaining districts and at different time periods.
- A comparison of soil fertility between different time periods is also possible with SFI. This will help in understanding the changes in soil fertility of the regions over time.

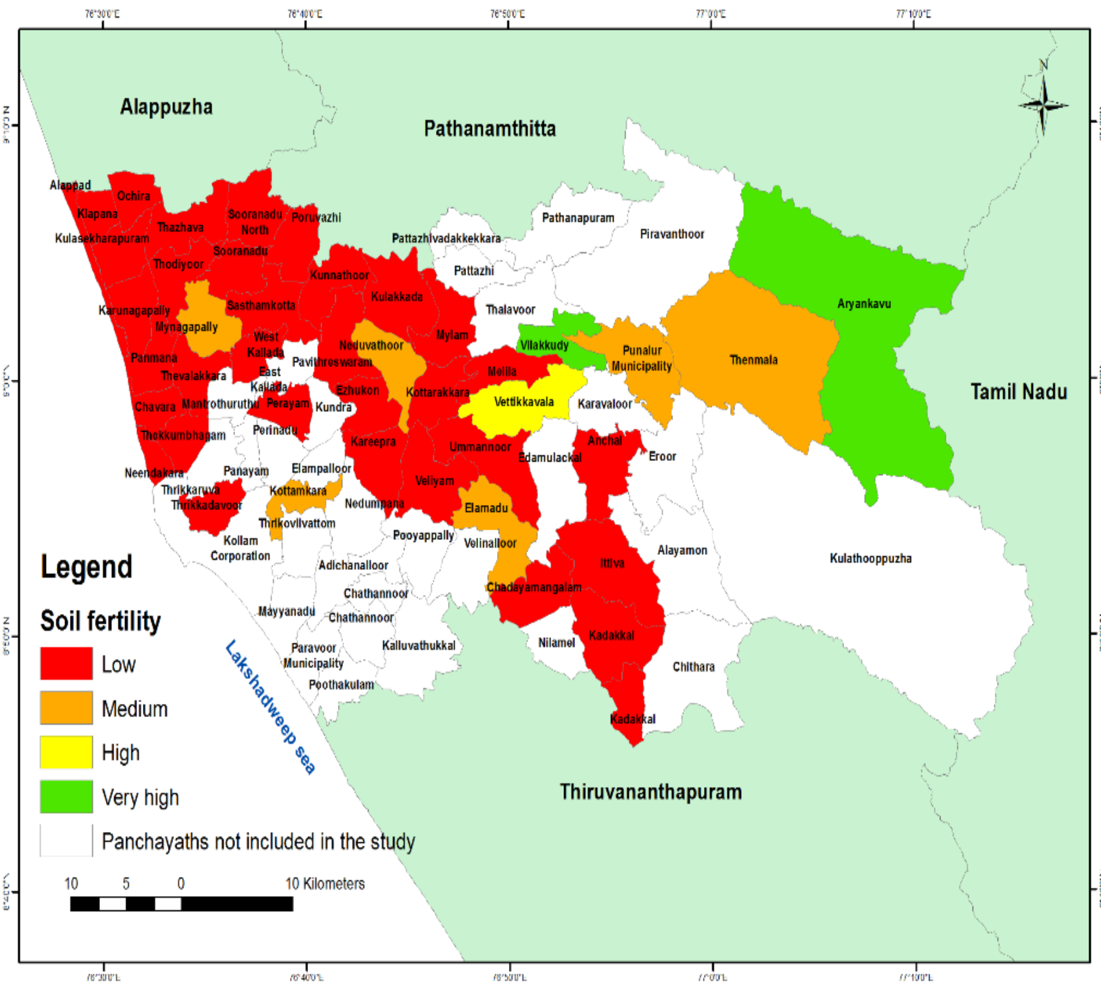


Fig.23. Map depicting soil fertility status of panchayats in Kollam

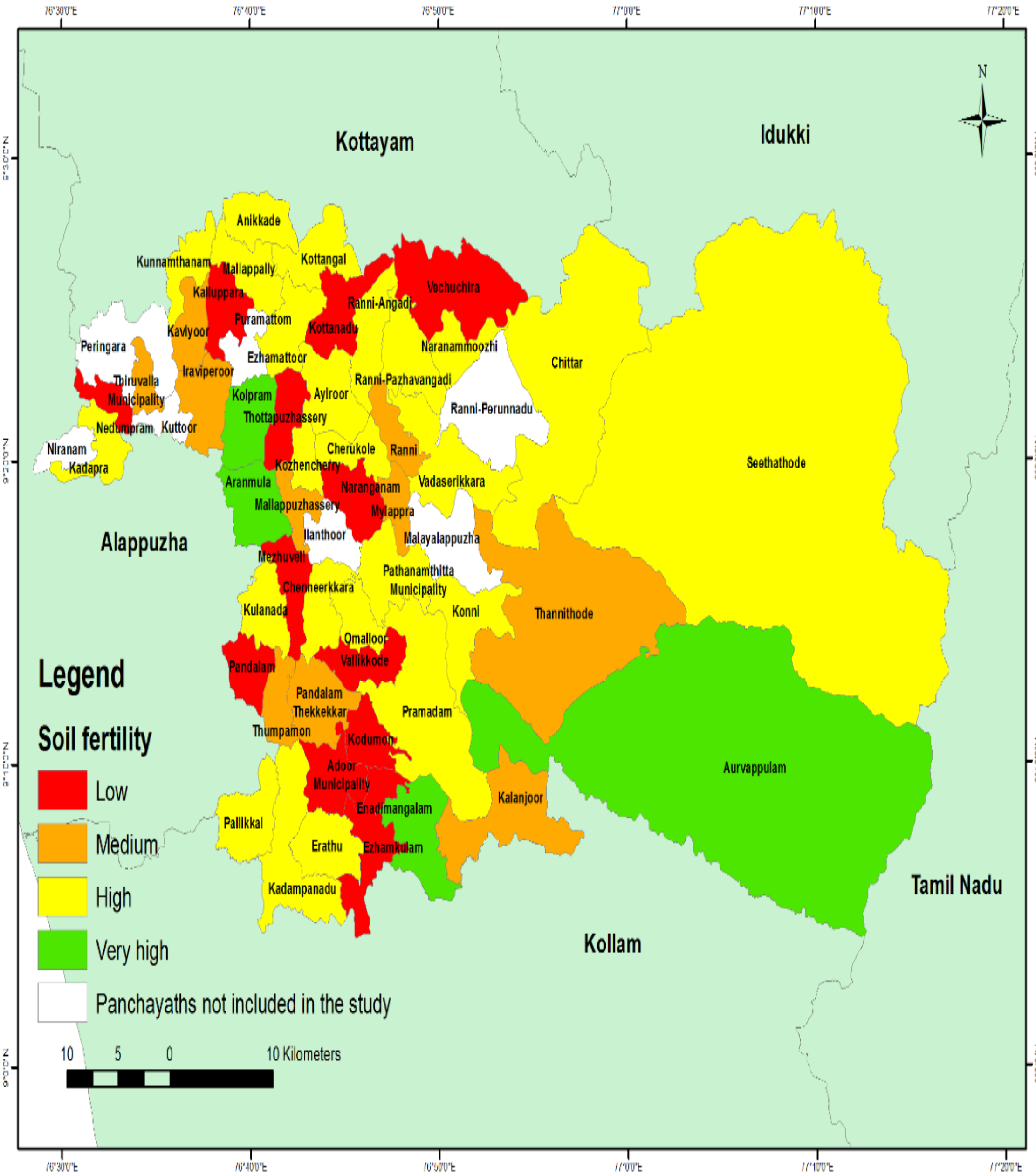


Fig.24. Map depicting soil fertility status of panchayats in Pathanamthitta

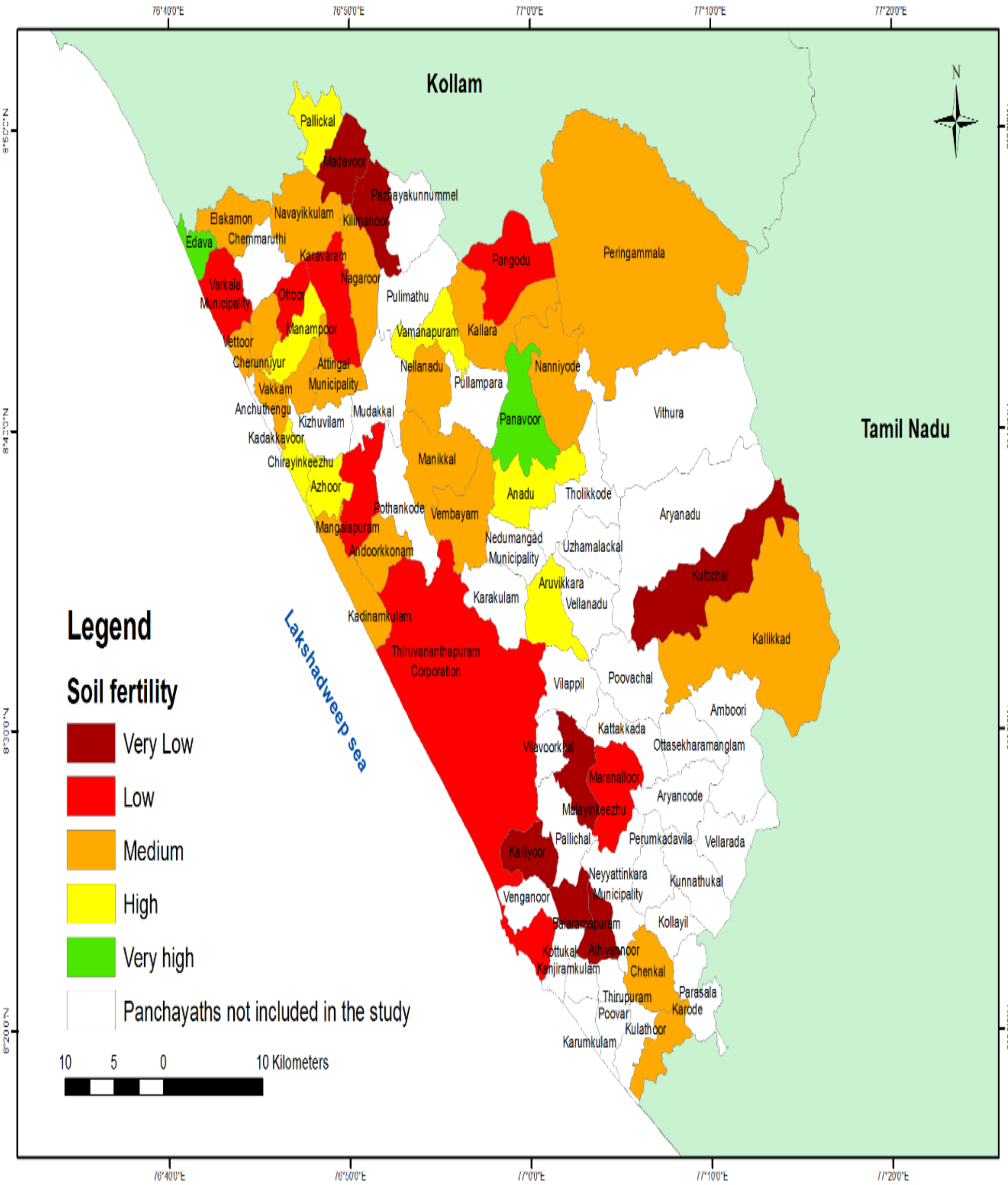


Fig.25. Map depicting soil fertility status of panchayats in Thiruvananthapuram

Summary

5. SUMMARY

Soil is the basic factor for sustenance of vegetation and it in turn supports all the life forms on earth and hence quality of the soil is essential in determining the productivity of the crops. The quality of soil implies its fertility in terms of macro and micronutrients for growing crops. Determination of soil fertility is important in predicting the productivity of the crops. Soil productivity can be defined as the capacity of a soil to produce crop per unit area. There are two types of soil fertility, inherent and acquired. Inherent soil fertility means, soil as a nature contains some nutrients, whereas, fertility induced by the application of manures, fertilizers, irrigation etc. is known as acquired fertility (Kanwar, 1976). Soil fertility can be assessed with the help of various soil parameters. An idea about the soil fertility beforehand can help to take necessary measures to improve the fertility status, which will later reflect on the yield of the crops. Since the soil varies from region to region, the same is seen in soil fertility, suggesting the need to determine fertility of a region which is rather useful for crop improvement activities. An understanding of this fact leads to the present study on regional soil fertility status.

The research work entitled 'Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis' was carried out at College of Agriculture, Vellayani during 2018-2020. The objective was to develop soil fertility status index to assess regional disparity among the panchayats of Thiruvananthapuram, Kollam and Pathanamthitta districts of southern Kerala and to classify the panchayats based on soil fertility index. Secondary data on 12 soil fertility parameters, collected as a part of Kerala State Planning Board Project conducted in 2013 were used for the analysis. The entire analysis was performed using the SPSS package.

Principal component analysis (PCA) and factor analysis were the multivariate techniques used in the study. The index of soil fertility was constructed using the results of PCA on the mean vector of soil fertility parameters of the panchayats. Index is a measure of a latent variable that can be constructed in several ways. Simple indexes, weighted aggregate index, index using PCA are some of them. Among them, the PCA based index was found to be the best one, since the weight assignment to the components is based on the proportion of variance explained by the components. However, in other cases weight assignment is purely subjective or on the basis of experts' reviews (Mukherjee and Lal, 2014). In this study an attempt was made to construct SFI as the weighted aggregation of PC scores. Factor analysis, a multivariate technique was also used in the study with the purpose to consider the soil fertility indicators that would create some regional variation in the construction of SFI to get a clear picture of regional fertility variation by including only those parameters in the SFI.

Initially 52 panchayats in Kollam, 57 panchayats in Pathanamthitta and 62 panchayats in Thiruvananthapuram were considered for the study. After the primary analysis using boxplots, outliers in the sample data were eliminated and the panchayats with more number of outliers were also eliminated. As a result, the number of panchayats considered in Kollam district reduced to 43 from 52, 50 from 57 in Pathanamthitta and 44 from 62 in Thiruvananthapuram district. The mean vector of 12 soil fertility parameters namely pH, EC, OC, P, K, Ca, Mg, S, B, Cu, Fe and Mn were estimated for the selected panchayats in each district separately.

In the case of Kollam, highest CV was shown by Cu (249.62 %) with a mean of 3.65 mg kg^{-1} and its values were observed in the range of 0.34 to 49.89 mg kg^{-1} followed by S (189%) and Fe (154.2%) with their mean values as 9.41 mg kg^{-1} and 37.31 mg kg^{-1} respectively. Range of values of S was observed to be 0.19 to 91.78 mg kg^{-1} and that of Fe was 7.07 to 391.84 mg kg^{-1}. Among all the parameters highest consistency was observed for pH with a mean value of 6.01 and values varied between 4.66 and 8.13. EC values varied between 0.03 and 0.73 dS m^{-1} showing a mean value 0.17 dS m^{-1} with a CV of 72.03 per cent. Almost a similar CV was observed for both OC (40.45 %) and P (44.94 %) with their values in the range of 0.46 to 2.06 per cent and 9.67 to 111.49 kg ha^{-1} respectively. OC status of Kollam was low to medium whereas that of P was high. Mean value corresponding to available K was 147.52 kg ha^{-1} with a CV of 92.32 per cent. K values were observed to be varied between 17.49 and 851.85 kg ha^{-1}. A CV of 74.16 per cent was observed in Ca with a lowest observed value 2.03 mg kg^{-1} and a highest value of 529.23 mg kg^{-1}. Range of available Mg content among 43 panchayats were 3.57 to 112.57 mg kg^{-1} with a CV of 77.63 per cent and a mean value of 33.78 mg kg^{-1} and most of the panchayats were deficient in Ca and Mg content. Among the micronutrients considered highest consistency was shown by B with a CV of 39.78 percent and the lowest observed value of B was 0.13 mg kg^{-1} and the highest was 1.17 mg kg^{-1}. Mean value of Mn was 17.47 mg kg^{-1} with a CV of 63.59 per cent. Available content of Mn varied between 2.33 and 46.32 mg kg^{-1}.

PCA extracted four principal components which were having eigen value more than one and accounted for 72.73 per cent variation in the data. Using the result of PCA, principal component scores were estimated by multiplying the mean vector of the panchayats with the coefficient matrix of extracted PCs. Each of these PC scores gives an idea about soil fertility status of the panchayats. But a more reliable estimate can be obtained by combining the information from all these PC scores. Hence a single valued soil fertility index (SFI) was constructed as the weighted aggregation of the PC scores. Weights corresponding to each PC score were estimated as the ratio of variance explained by each PC to the cumulative variance of all the extracted PCs (Krishnan, 2010). The weights of four PCs thus estimated for Kollam were 0.52, 0.21, 0.15 and 0.12. SFI constructed for Kollam was found to be low at Alappad panchayat (16.34) and high at Aryankavu panchayat (435.12) having a mean of 111.31 and a CV of 82.45 per cent. Factor analysis was performed on the mean vector in order to extract the relevant parameters and it resulted in the elimination of pH, EC, Mg, B and Mn in Kollam which were reported to have low factor loadings and communality below 50 per cent. PCA was repeated on the remaining data and all the procedures to construct SFI were again performed. The SFI- FA was found to have a mean of 122.62 with a CV of 94.67 per cent which was more than that of the initial CV. With respect to SFI-FA also, Alappad (9.49) was found to have low soil fertility and Aryankavu (547.41) possesses the highest. After the estimation of SFI, they were normalized by min-max normalization and the panchayats were classified into four groups based on SFI and SFI- FA into (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%). In Kollam about 70 per cent of the panchayats were included in low fertility class with respect to initial SFI and 79 per cent with respect to SFI- FA. The soils in the panchayats listed in the low fertile category reported to have deficiency of Ca, Mg, S and Cu.

Similar analysis was done in Pathanamthitta and Thiruvananthapuram. While considering Pathanamthitta, pH was observed to have high consistency with a CV of

8.92 per cent with its values in the range 4.20 to 6.56 and EC was observed to be the least consistent with CV 159.30 percent. EC values showed a variation from 0.06 to 2.75 dS m^{-1}. CVs of 27.70 and 28.80 per cent were observed for OC and K respectively with their values in the range 0.64 to 3.26 per cent and 148.32 to 475.67 kg ha^{-1}. CV of P was 61.85 per cent with mean value 66.62 kg ha^{-1}. Lowest observed value of P was 4.63 kg ha^{-1} and highest was 195.87 kg ha^{-1}. Ca content had shown variation from 82.10 to 1000.00 mg kg^{-1}. Mean value of Ca was 634.92 mg kg^{-1} with a CV of 48.60 per cent. Values of Mg were in the range 26.62 to 461.50 mg kg^{-1} showing 94.30 percent CV. CV of S was 36.89 percent with mean value 20.60 mg kg^{-1}. 1.30 mg kg^{-1} was the lowest observed S content among 50 panchayats and 25.00 mg kg^{-1} was the highest. After EC the next highest CV (102.39 %) was observed for B with values in the range 0.05 to 3.06 mg kg^{-1} but it was reported to be deficient in most of the panchayats. CV of Cu and Fe was 35.86 per cent and 41.56 per cent respectively with their mean values as 2.73 mg kg^{-1} and 35.20 mg kg^{-1}. Mean value corresponds to Mn was 28.80 mg kg^{-1} with a CV of 63.17 per cent. Values of Mn varied between 3.73 to 69.88 mg kg^{-1} indicating the adequate availability of Mn in all the panchayats.

PCA on mean vector data of Pathanamthitta resulted in the extraction of four PCs which accounted for 68.70 per cent variation in the data. SFI constructed by weighted aggregation of four PC scores was reported to be highest at Thottapuzhaserry panchayat (46.99) and was lowest at Aruvappulam panchayat (248.48) with mean of 131.75 and a CV of 33.49 per cent. The low CV implies the more similarity in soil fertility among the panchayats of Pathanamthitta. Five parameters namely OC, Cu, K, B and Mn were observed to have low communality and hence precluded from analysis. The SFI recalculated based on the remaining seven parameters had CV 38.30 per cent and mean 185.90. Classification of panchayats based on normalized index resulted in the inclusion of 36 per cent of the panchayat under the medium fertility group with respect to initial SFI and 48 per cent under high fertility category based on SFI- FA. Good soil fertility status of Pathanamthitta can be attributed to the medium to high availability of most all the soil parameters like OC, P, K, S, Cu, Fe and Mn in the soils.

Similar to the observation in Pathanamthitta in Thiruvananthapuram also has shown highest consistency in pH with a CV of 3.67 percent with values in the range 5.01 to 6.32 whereas least consistency was observed for EC (152.15 %) with its values varied between 0.04 to 2.36 dS m^{-1}. After EC, the next highest CV was observed for Cu (130.98 %) with a mean value of 4.60 and lowest observed value as 0.08 mg kg^{-1} and highest as 37.71 mg kg^{-1}. CV of OC was 37.58 per cent with mean 1.00 per cent and values in the range 0.48 to 1.70 per cent. P values varied between 13.11 kg ha^{-1} and 38.94 kg ha^{-1} with CV of 28.17 per cent. Mean value of K was 177.01 kg ha^{-1} and CV was 80.66 per cent with its values in the range 29.54 to 550.05 kg ha^{-1}. CV of Ca was 34.94 per cent with the majority of the panchayats having available Ca above 300 mg kg^{-1}. Mg availability varied between 29.60 to 200.79 mg kg^{-1} and that of S was 12.00 to 61.38 mg kg^{-1} with a CV of 45.30 per cent. There observed a similarity in CV of B and Fe which were 54.24 per cent and 59.15 per cent respectively with their values in the range of 0.11 to 0.88 mg kg^{-1} and 1.17 to 238.93 mg kg^{-1}. There observed an adequacy in Fe and Mn availability but B was deficient and the CV of Mn was 39.02 per cent with a mean of 36.90 mg kg^{-1} in the range from 1.08 to 58.27 mg kg^{-1}.

In Thiruvananthapuram five PCs which accounted for 75.06 percent variation of the data were extracted from PCA. SFI had a mean of 95.93 and a CV of 27.68 per cent indicating consistency in soil fertility among the panchayats in Thiruvananthapuram as compared to that of Pathanamthitta. All the parameters were reported to have high factor loading on the extracted factors. Hence it was concluded that all the parameters were found to be relevant in explaining the variation in soil fertility of Thiruvananthapuram. The classification of panchayats based on normalized SFI indicated medium fertility status (51.35%) of the district and almost all the parameters except B and Mg were found to be sufficiently available in most of the panchayats in Thiruvananthapuram.

The results of the study based on the developed SFI confirmed inter-regional disparity between panchayats within each district as well as between districts. The soil fertility status of panchayats in Kollam was poor as compared to Panchayats in Pathanamthitta and Thiruvananthapuram, but soil fertility status of Panchayats in Thiruvananthapuram was low as compared to Pathanamthitta. This finding was statistically supported by the Kruskal-Wallis test.

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INTER-REGIONAL DISPARITY IN SOIL FERTILITY STATUS OF SOUTHERN KERALA – A STATISTICAL ANALYSIS

by

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Abstract of thesis

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ABSTRACT

The research work entitled ‘Inter-regional disparity in soil fertility status of southern Kerala – a statistical analysis’ was carried out at College of Agriculture Vellayani during 2018-2020. The objective was to develop soil fertility status index to assess regional disparity among the panchayats of Thiruvananthapuram, Kollam and Pathanamthitta districts of southern Kerala and to classify the panchayats based on soil fertility index. Secondary data on 12 soil fertility parameters, collected as a part of Kerala State Planning Board Project conducted in 2013 were used for the analysis. Detection and elimination of outliers using box plot was the first step in the analysis followed by estimation of mean vector of 12 soil fertility parameters from 43 panchayats of Kollam, 50 panchayats of Pathanamthitta and 44 panchayats of Thiruvananthapuram. The descriptive statistics used include range, mean and coefficient of variation (CV) of all the parameters. The entire analysis was done with the help of SPSS software.

Among the 12 soil fertility parameters the range of Cu (0.34 - 49.89 mg kg^{-1}), S (0.19 - 91.78 mg kg^{-1}) Fe (7.07 - 391.84 mg kg^{-1}) and K (17.49 - 851.85 kg ha^{-1}) was observed to be very high with CV 249.62, 188.98, 154.22 and 92.32 per cent respectively in Kollam district. This is an indication of deficiency to above adequate availability of these nutrients in the panchayats. Among all the parameters highest consistency was observed in pH with mean value of 6.01 and the values varied between 4.66 and 8.13. EC values varied between 0.03 and 0.73dS m^{-1} showing a mean valueof 0.17 dS m^{-1} with a CV of 72.03 per cent. Almost a similar CV was observed for both OC (40.45 %) and P (44.94 %) with their values in the range 0.46 to 2.06 per cent and 9.67 to 111.49 kg ha^{-1} respectively. There observed a wide spread deficiency of Ca and Mg in almost all the panchayats. Among the micronutrients considered highest consistency was shown by B with a CV of 39.78 per cent and the lowest observed value of B was 0.13 mg kg^{-1} and the highest was 1.17 mg kg^{-1}. Mean value of Mn was 17.47 mg kg^{-1} with a CV of 63.59 per cent. Available content of Mn varied between 2.33 and 46.32mg kg^{-1}.

PCA (Principal Component Analysis) performed on the mean vector of 12 soil fertility parameters of 43 panchayats in Kollam, extracted four PCs which accounted

for 72.73 per cent variation of the data and based on the extracted PCs weighted aggregate index known as Soil Fertility Index (SFI) was developed to quantify the soil fertility status. The SFI thus estimated varied from 16.34 to 435.12 in Kollam with a mean of 111.31 and CV of 82.45 per cent. Further, factor analysis was performed to reduce the dimension and the soil nutrients P, Ca, K, OC, Fe, S and Cu had loading above 0.5 with a communality of more than 50 percent were retained and PCA was repeated and SFI was re-estimated. The estimated SFI was normalized using min-max normalization and based on this, the panchayats were grouped into four categories as low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%). In Kollam about 70 per cent of the panchayats were included in low fertility class with respect to initial SFI and 79 per cent with respect to SFI- FA. The soils in the panchayats listed in the low fertile category reported to have deficiency in Ca, Mg, S and Cu.

While considering Pathanamthitta, EC has shown highest CV with its values range from 0.06 to 2.75 dS m^{-1}. All the soil nutrients except B and Mg were adequate in the soils of most of the Panchayats in Pathanamthitta. pH was said to have high consistency with a CV of 8.92 per cent with its values in the range 4.20 to 6.56. CV of 27.70 and 28.80 per cent were observed for OC and K respectively with their values in the range of 0.64 to 3.26 per cent and 148.32 to 475.67 kg ha^{-1}. CV of P was 61.85 per cent with mean value 66.62 kg ha^{-1}. Lowest observed value of P was 4.63kg ha^{-1} and highest was 195.87 kg ha^{-1}. Ca content had shown variation from 82.10 to 1000.00 mg kg^{-1}. Mean value of Ca was 634.92 mg kg^{-1} with a CV of 48.60 per cent. Values of Mg were in the range of 26.62 to 461.50 mg kg^{-1}showing 94.30 per cent CV. CV of S was 36.89 per cent with mean value 20.60 mg kg^{-1}. A CV of 102.39 per cent was observed for B with values in the range 0.05 to 3.06 mg kg^{-1}. CV of Cu and Fe was 35.86 per cent (for values between 0.87 to 5.51 mg kg^{-1}) and 41.56 per cent (values in the range 20.27 to 101.62mg kg^{-1}) respectively with their mean values as 2.73 mg kg^{-1} and 35.20 mg kg^{-1}. Values of available Mn varied between 3.73 to 69.88 mg kg^{-1} with a CV of 63.17 per cent.

PCA extracted four PCs which accounted for 68.70 per cent variation in the data. The mean and CV of the estimated SFI of Panchayats were respectively 131.75 and 33.49 based on initial PCA. The parameters OC, Cu, K, B and Mn were exempted based on factor analysis and the mean and CV of SFI- FA was respectively 185.90 and

38.30 per cent. Classification based on SFI- FA has shown an improvement in fertility status and the results of classification revealed that about 56 percent Panchayats were in high to very high soil fertility category in Pathanamthitta.This was because the relatively good availability of most of the soil parameters like OC, P, K, S, Cu, Fe and Mn in the panchayats of Pathanamthitta.

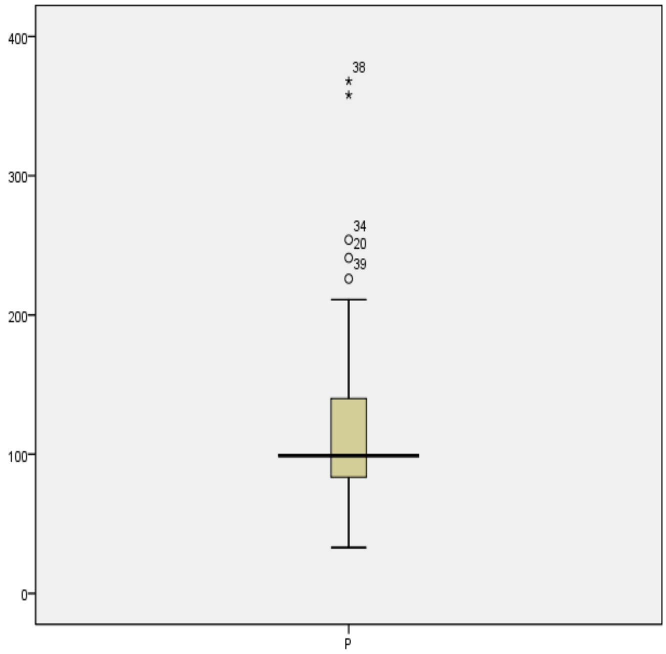
In Thiruvananthapuram also more consistency was shown by pH with a CV of 3.67 per cent with values in the range 5.01 to 6.32. Most of the soil fertility parameters except EC (152.15%), Cu (130.98%), K (80.66%), B (54.24%) and Fe (59.15%) were found to have CV below 50 percent indicating less variability among the Panchayats in Thiruvananthapuram. The range of values of OC and P were respectively 0.48 to 1.70 percent, 13.11 to 38.94 kg ha^{-1}. CV of Ca was 34.94 per cent with majority of the panchayats having available Ca above 300 mg kg^{-1}. For Ca, lowest value observed was 170.80 mg kg^{-1} and highest value was 882.50 mg kg^{-1}. Mg availability varied between 29.60 to 200.79 mg kg^{-1} and that of S was 12.00 to 61.38 mg kg^{-1}. There noticed an adequacy in Fe and Mn availability but B was deficient. PCA extracted five PCs which accounted for 75.06 per cent variation in Thiruvananthapuram. SFI constructed had a mean of 95.93 with a CV of 27.68 per cent. The result of factor analysis concluded that all the parameters were found to be relevant in explaining the variation in soil fertility. Based on SFI, it was observed that 51.35 percent of panchayats in Thiruvananthapuram were in the medium fertility status category with almost all the parameters were found to be sufficiently available in most of the panchayats except B and Mg in Thiruvananthapuram.

The results of the study based on the developed SFI confirmed inter-regional disparity between panchayats within in each district as well as between districts. The soil fertility status of panchayats in Kollam was poor as compared to Panchayats in Pathanamthitta and Thiruvananthapuram, but soil fertility status of Panchayats in Thiruvananthapuram was low as compared to Pathanamthitta and this conclusion was statistically supported by Kruskal-Wallis test.

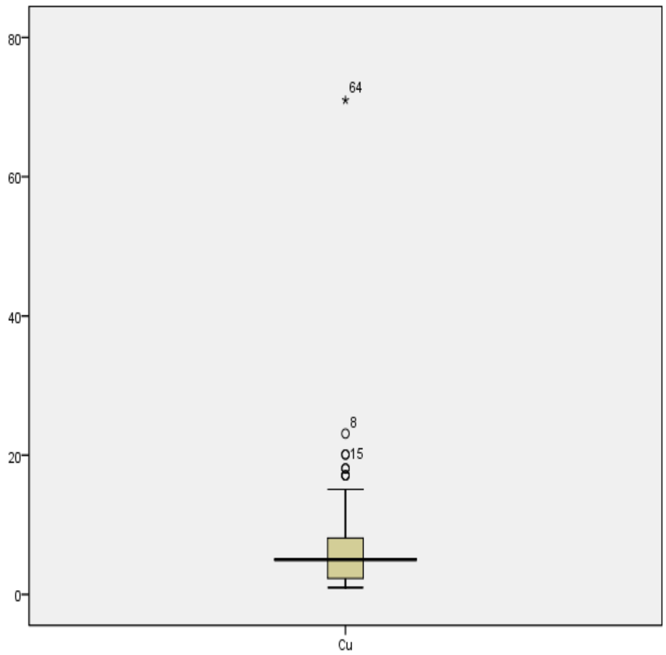
Appendices

Appendix 1

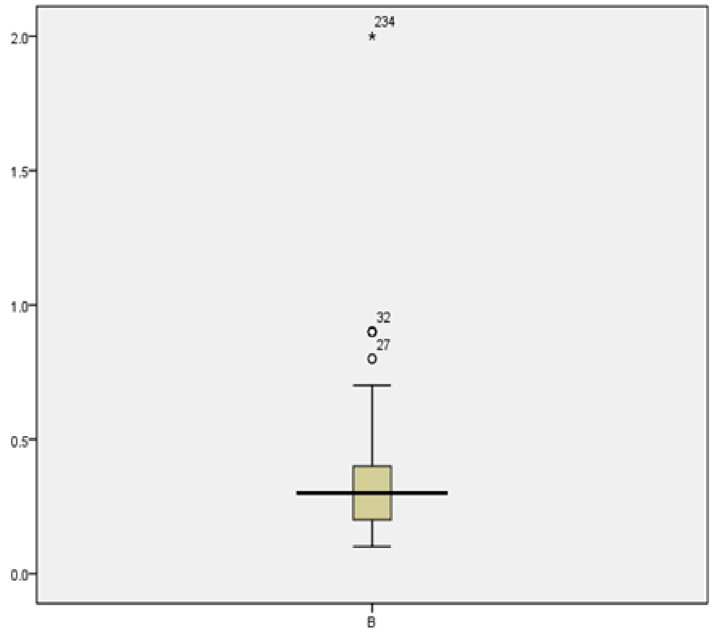
Box Plots of soil fertility parameters in Kollam



P

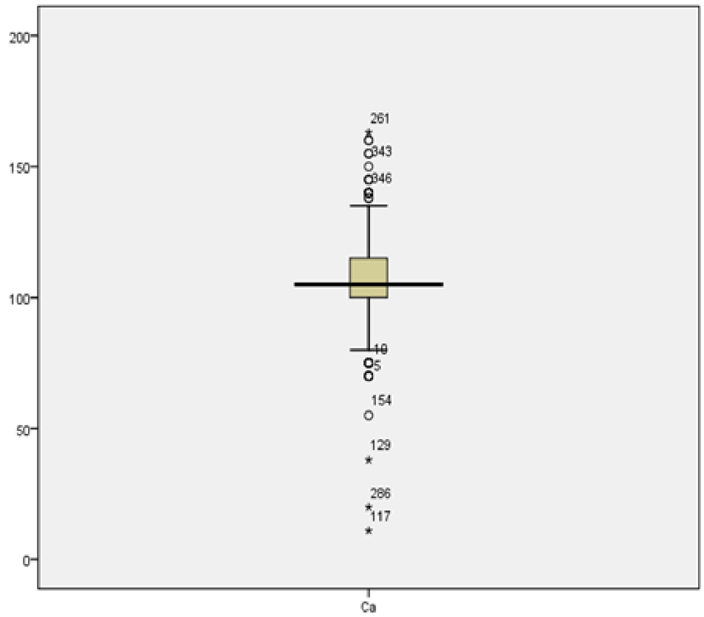


Cu



2.0
1.5
1.0
0.5
0.0
234
32
27
B

B

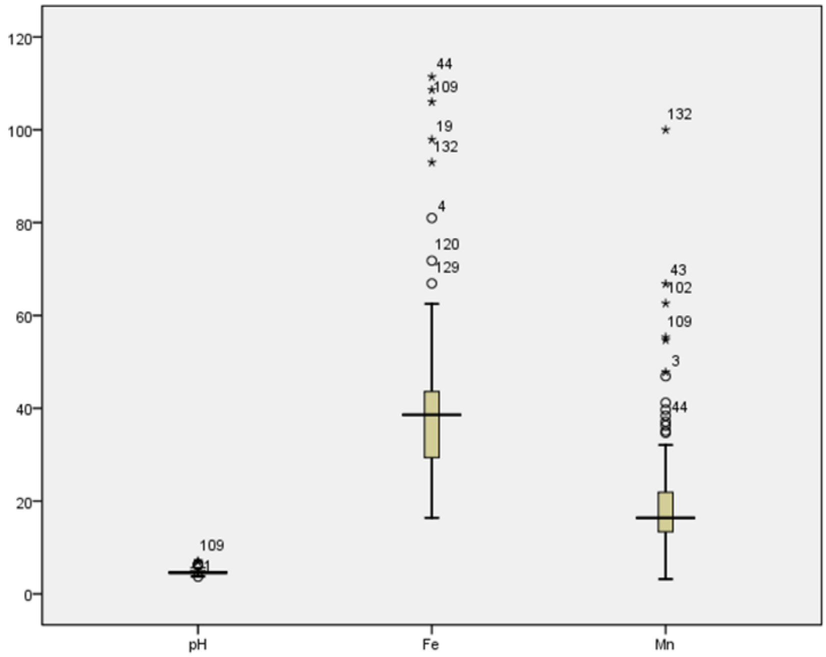


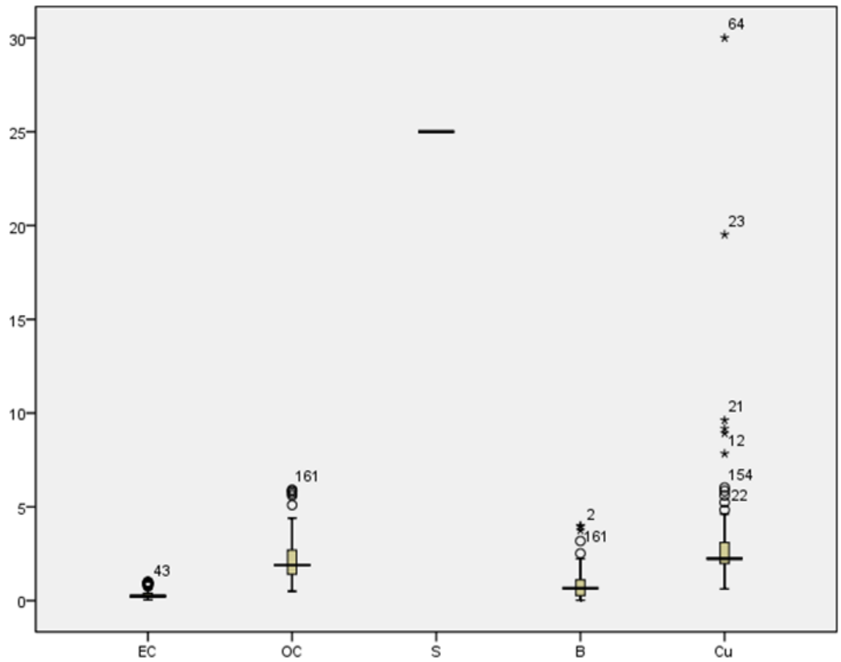
200
150
100
50
0
261
343
346
154
129
286
117
Ca

Ca

Appendix 2

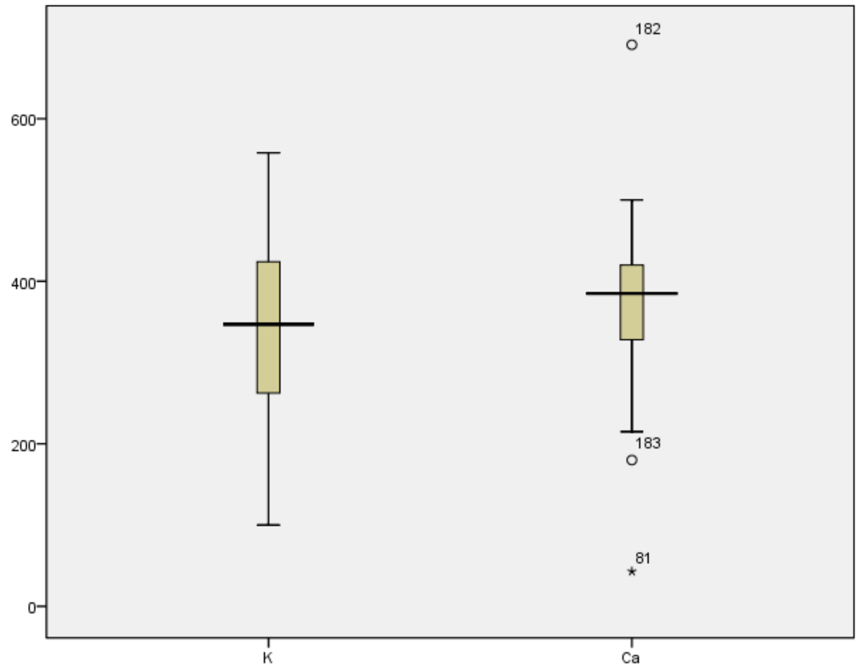
Box plots of soil fertility parameters in Pathanamthitta

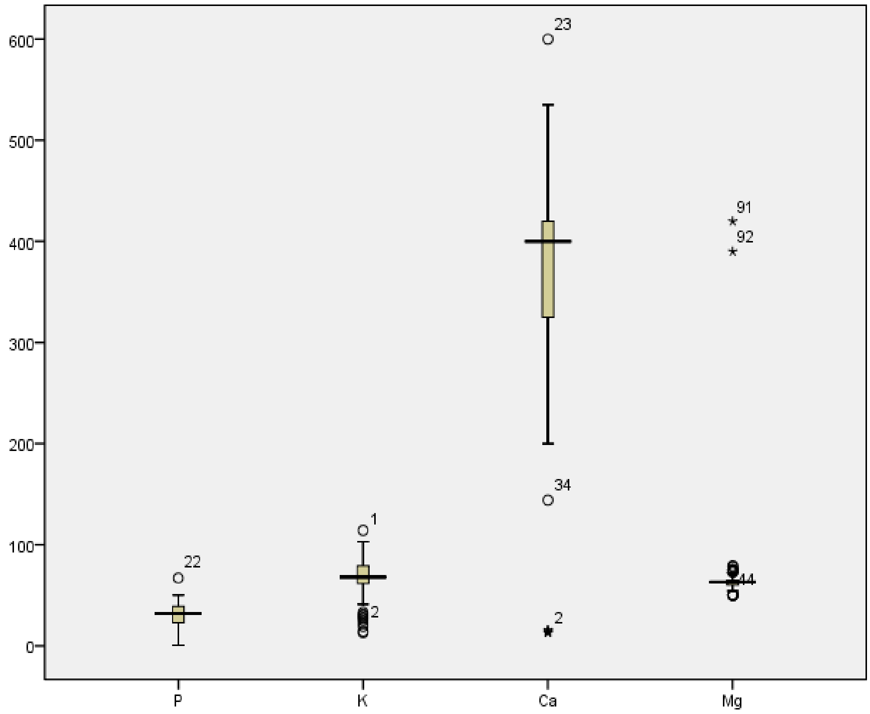




Appendix 3

Box plots of soil fertility parameters in Thiruvananthapuram





Appendix 4

Mean and CV of soil fertility parameters of 43 panchayats in Kollam district.

Descriptive	**pH**	**EC ($dS\ m^{-1}$)**	**OC (%)**	**P ($kg\ ha^{-1}$)**	**K ($kg\ ha^{-1}$)**
Mean	6.01 (4.66- 8.13)	0.17 (0.03-0.73)	0.83 (0.46- 2.06)	57.59 (9.67- 111.29)	147.52 (17.49- 851.85)
CV (%)	10.99	72.03	40.45	44.94	92.32

Descriptive	**Ca ($mg\ kg^{-1}$)**	**Mg ($mg\ kg^{-1}$)**	**S ($mg\ kg^{-1}$)**	**B ($mg\ kg^{-1}$)**	**Cu ($mg\ kg^{-1}$)**	**Fe ($mg\ kg^{-1}$)**	**Mn ($mg\ kg^{-1}$)**
Mean	162.43 (2.03- 529.23)	33.78 (3.57- 112.57)	9.41 (0.19-91.78)	0.64 (0.13-1.17)	3.65 (0.34 - 49.89)	37.3 (7.07-391.84)	17.47 (2.33- 46.32)
CV (%)	74.16	77.63	188.98	39.75	249.62	154.22	63.59

Appendix 5

Mean and CV of soil fertility parameters of 50 panchayats in Pathanamthitta district.

Descriptive	**pH**	**EC ($dS\ m^{-1}$)**	**OC (%)**	**P ($kg\ ha^{-1}$)**	**K ($kg\ ha^{-1}$)**
Mean	5.19 (4.20 - 6.56)	0.33 (0.06 - 2.75)	1.65 (0.64 - 3.26)	66.62 (4.63- 195.87)	291.18 (148.32 - 475.67)
CV (%)	8.92	159.30	27.70	61.85	28.80

Descriptive	**Ca ($mg\ kg^{-1}$)**	**Mg ($mg\ kg^{-1}$)**	**S ($mg\ kg^{-1}$)**	**B ($mg\ kg^{-1}$)**	**Cu ($mg\ kg^{-1}$)**	**Fe ($mg\ kg^{-1}$)**	**Mn ($mg\ kg^{-1}$)**
Mean	634.92 (82.10- 1000.00)	142.14 (26.62- 461.50)	20.60 (1.30- 25.00)	0.67 (0.05 -3.06)	2.73 (0.87- 5.51)	35.20 (20.27-101.62)	28.80 (3.73-69.88)
CV (%)	48.60	94.30	36.89	102.39	35.86	41.56	63.17

Appendix 6

Mean and CV of soil fertility parameters of 37 panchayats in Thiruvananthapuram district.

Descriptive	**pH**	**EC ($dS\ m^{-1}$)**	**OC (%)**	**P ($kg\ ha^{-1}$)**	**K ($kg\ ha^{-1}$)**
Mean	6.12 (5.01 - 6.32)	0.24 (0.04 - 2.36)	1.00 (0.48-1.70)	22.82 (13.11 - 38.94)	177.01 (29.54 -550.05)
CV (%)	3.67	152.15	37.58	28.17	80.66

Descriptive	**Ca ($mg\ kg^{-1}$)**	**Mg ($mg\ kg^{-1}$)**	**S ($mg\ kg^{-1}$)**	**B ($mg\ kg^{-1}$)**	**Cu ($mg\ kg^{-1}$)**	**Fe ($mg\ kg^{-1}$)**	**Mn ($mg\ kg^{-1}$)**
Mean	386.12 (170.80 - 882.50)	59.82 (29.60-200.79)	20.42 (12.00 - 61.38)	0.30 (0.11-0.88)	4.60 (0.08 - 37.71)	93.24 (1.17-238.93)	36.90 (1.08-58.27)
CV (%)	34.94	41.57	45.30	54.24	130.98	59.15	39.02