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PCA based index to measure the soil fertility status of panchayats in Pathanamthitta district, Kerala

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Abstract

Soil fertility is an indication of productivity of soil, which can be assessed with the help of available soil nutrient parameters. Assessment of soil fertility of the regions facilitates better fertilizer recommendations for each region separately. However, since the availability of soil nutrient parameters vary from region to region, assessment of soil fertility based on an index comprising of soil nutrient parameters may be preferred. In this context an attempt was made in this paper to construct a single value Soil Fertility Index (SFI) of 50 panchayats in Pathanamthitta district in Kerala, using 12 soil nutrient parameters namely, pH, EC, OC, P, K, Ca, Mg, S, B, Cu, Fe and Mn. Principal Component Analysis transform the original variables to orthogonal linear combinations by providing weights to each variable and was performed here initially to determine weights of 12 soil nutrient parameters and four principal components which accounted for around 68 per cent variation in the soil nutrient data were retained. The weighted aggregation of four principal component scores with weight as share of variance of each component was considered as the SFI. The estimated SFI of 50 panchayats varied from 46.99 (Thottapuzhaserry panchayat) to 248.48 (Aruvappulam panchayat) with 33.49 per cent coefficient of variation. Further the index was normalized and the panchayats were grouped into low (SFI from 0%-25%), medium (25%-50%), high (50%-75%) and very high (75%-100%) fertile based on normalized index.

Keywords: Descriptive statistics, principal component analysis, soil fertility index, soil fertility parameters

Introduction

Agricultural production is one of the major factors on which life on earth is relied upon. It possesses a direct relationship with soil productivity, which is the capacity of a soil to produce crop per unit area. This productivity is in turn influenced by soil fertility, it is nothing but the ability of soil to provide adequate soil nutrients (Kanwar, 1976) ^[7]. Hence in order to manage the agricultural production, an idea regarding the soil fertility is mandatory. In order to probe soil fertility, knowledge about the available soil nutrient content is required. An idea of fertility status of different regions will give a way to have a comparison among the regions and will help in classifying the regions according to fertility status (Khokhar, 2008) ^[10]. It also helps to identify the difference between actual productivity and potential productivity of each region. This can be made use in adopting necessary steps to improve the regional production. But the assessment of fertility based on single nutrients alone is not exactitude (Kavitha and Sujatha, 2015) ^[8]. Hence an attempt was made in this paper to assess the soil fertility status of 50 panchayats in Pathanamthitta district in Kerala state using 12 soil parameters namely, pH, EC, OC, P, K, Ca, Mg, S, B, Cu, Fe and Mn by constructing a single value fertility status index corresponding to each panchayats.

Study on soil fertility status of RARS, Tarahara, Nepal by Khadka *et al.* (2017) ^[9] necessitates the adoption of proper nutrient management during crop cultivation where the nutrient index was constructed using various soil parameters like pH, organic matter, N, P₂O₅, K₂O, Ca, Mg, S, B, Fe, Zn, Cu and Mn.

Materials and Methods

The present study is based on secondary data on soil pH, EC, macro and micronutrients of 50

panchayats in Pathanamthitta district. Initially Box plot for the soil nutrient parameters were constructed to detect and remove the outliers in the observations. The descriptive statistics including mean and coefficient of variation calculated to get an idea about the variability of the parameters. In order to identify areas having low to high soil fertility, the study has tried to estimate a soil fertility status index using available nutrient parameters of the soil by PCA. Secondary data on available soil parameters of Pathanamthitta district of Kerala were obtained from Kerala State Planning Board Project conducted in 2013 [12]. PCA is a multivariate technique mainly used for dimensionality reduction of large data set to a small number of linear combinations. PCA will convert large number of dependent variables into new set of variables called as principal components, which are the linear combination of the original variables and are orthogonal to each other (Abdi and Williams, 2010) [1]. The first principal component is the one which account for more amount of variation in the data and second one will be orthogonal to the first principal component and will explain the next highest variation which is not explained by the first one and so on. Principal components are selected in the dimension where the variance can be maximized. It can be obtained by rotating the axes.

Let $Z_i = a_i^T y_i$, $A = (a_1, a_2, \dots, a_p)^T$, A is an orthogonal matrix. Here y_i changed to Z_i , having same distance from origin but the axis have rotated (Rencher, 1934) [13]. Likewise, the suitable dimensions can be identified. The new points $Z_1, Z_2, \dots, Z_p$ thus obtained represent the principal components such that $S^T = ASA^T$ is the dispersion matrix of Z

S = Dispersion matrix of y_i

a_i is chosen such that $a_i^T a_i = 1$. The diagonal elements of dispersion matrix represent the eigen values. i.e., $\text{tr}(S) = \sum_{i=1}^p \lambda_i$ (Chatfield and Collins, 1980) [5]

This eigen value corresponds to each principal component represents the variance explained by that principal components. So the proportion of variance explained by i^{th} principal component,

$$PC_i = \frac{\lambda_i}{\sum_{i=1}^p \lambda_i}$$

In order to construct the index only those principal components having eigen value more than one will be used. From the extracted PCs, principal component scores are obtained by multiplying the data matrix with the coefficient matrix of extracted PCs. Weighted aggregation of these principal component scores produce the 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:

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

Where,

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

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

V_j = Coefficient matrix of extracted principal components.

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

Index thus constructed will be normalized by min- max normalization given by the equation

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

Results and Discussion

Descriptive statistics

Mean value and CV of 12 soil parameters corresponds to each panchayat were obtained from sample data. pH showed highest consistency with a CV of 8.92 per cent. EC ranges from 0.06 dS m^{-1} to 2.75 dS m^{-1} with a CV of 159.30 per cent. CV of OC was 27.70 per cent with a mean value of 1.65 per cent. CV of 61.85 per cent was noticed in P with a mean value of 66.62 kg ha^{-1} . Availability of K varied between 148.32 to 475.67 kg ha^{-1} with a CV of 28.80 per cent. Lowest amount of observed Ca content was 82.10 mg kg^{-1} and highest was 1000 mg kg^{-1} with a CV of 48.60 per cent. CV of Mg was 94.30 per cent. Mean value of S was 20.60 mg kg^{-1} showing a CV of 36.89 per cent.

B was found to be deficient in most of the panchayats with a CV of 102.39 per cent. CV of Cu was 35.86 per cent with a mean value of 2.73 mg kg^{-1} . Fe also exhibited a similar CV of 41.56 per cent. Mean value corresponds to Mn was 28.80 mg kg^{-1} with a CV of 63.17 per cent.

Principal component analysis

Principal component analysis was performed as the basic method to identify the variation in soil fertility status of 50 panchayats in Pathanamthitta district. An index corresponds to each panchayat, which was constructed by the method of PCA is supposed to represent its fertility status. The results of PCA on mean vector of 50 panchayats in Pathanamthitta are presented in Table 1. The first four principal components having eigenvalue more than one and accounted for more than 68 per cent variation in the data were retained for the construction the index.

Table 1: Results of PCA on mean data of Pathanamthitta

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

Total 12 principal components were obtained from PCA using correlation matrix of soil parameters of 50 Panchayats and among them only the first four were having eigenvalue above one. The first principal component account for 29.22 per cent variation in the data followed by 19.63, 10.75 and 9.10 per cent variations respectively by the other three components. Altogether the four PCs account for 68.70 per cent variation in

the data. In PC 1 highest coefficient was for Fe (0.85) followed by pH (0.80). While considering PC 2, Ca possessed highest coefficient value of 0.79 and S had a coefficient loading of 0.12 on PC 2. S was reported to have high loading on PC 3 and PC 4. The four PCs which were extracted based on KMO criteria were retained for index construction. Based on the first and second principal components, score plot was obtained to identify the soil fertility similarities among the panchayats (Fig. 1).

Construction of index

After extracting the PCs, the PC scores were obtained by multiplying the mean vector of 50 panchayats with the eigenvector matrix (Coefficient matrix) of extracted four PCs. Thus four PC scores were obtained and each of these scores can be considered as an indication of soil fertility status. But a more reliable index of soil fertility can be obtained as the weighted aggregation of the PC scores. Weight correspond to each PC score was calculated as the proportion of variance explained by each PC to the cumulative variance of all the four PCs. Thus the weight of four PC scores were estimated as 0.425, 0.286, 0.157 and 0.132 respectively. The Soil Fertility Index was calculated as the weighted aggregation of PC scores followed by min-max normalization. The estimated SFI and normalized index are given in Table 2.

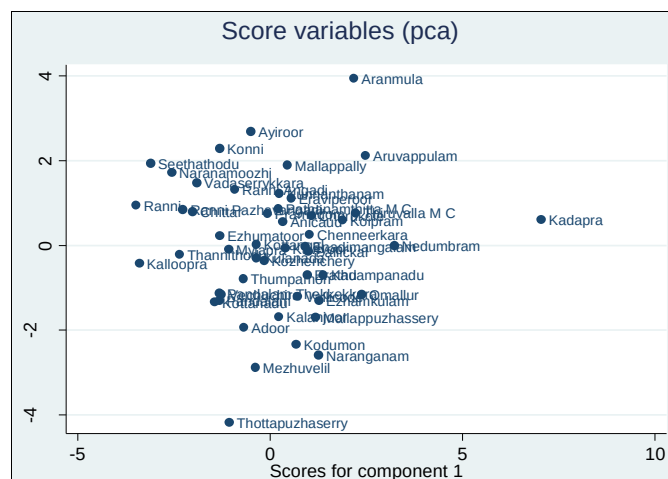


Fig 1: Score plot of PCA

Based on the score plot, the panchayats which comes closer in the same quadrant can be grouped under same soil fertility category. The panchayats which are at long distance from origin can be considered as the predominantly different ones. The inference obtained from score plot is on par with the classification of panchayats (Table 3).

Table 2: SFI of 50 panchayats of Pathanamthitta district

Panchayats/Index	I	I Normalized	Panchayats/Index	I	I Normalized
Adoor	78.02	0.15	Kunnnanthanam	169.21	0.61
Anicaud	159.28	0.56	Mallappally	182.18	0.67
Aranmula	197.94	0.75	Mallappuzhaserry	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

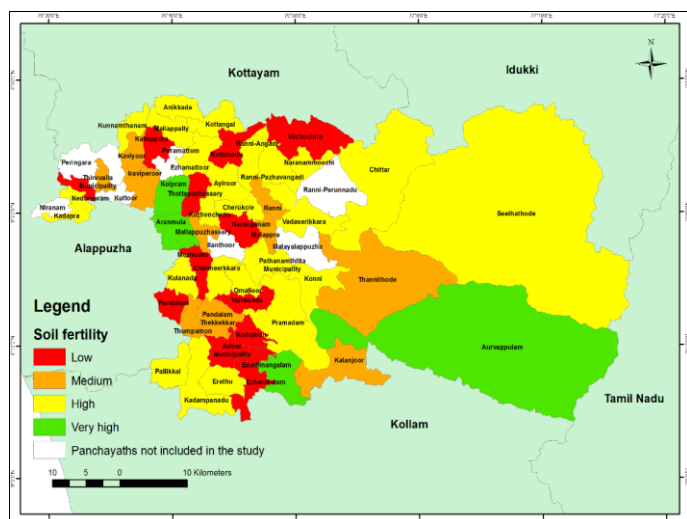
Index value showed a variation from lowest value of 46.99 (Thottapuzhaserry panchayat) to highest value of 248.48 (Aruvappulam panchayat) with 33.49 per cent coefficient of variation and mean value 131.75. More than 50 per cent of the panchayats in Pathanamthitta were reported to have an index

above the mean value. This roughly indicate the good soil fertility of Pathanamthitta district. Based on the index constructed, panchayats were grouped into four categories as low (SFI from 0-25%), medium (25-50%), high (50-75%) and very high (75-100%) and presented in Table 3.

Table 3: Classification of panchayats based on SFI

Groups (based on SFI) (%)	Name of the Panchayats	Number of panchayats
Low (0-25%)	Adoor, Ezhamkulam, Kalloopra, Kodumon, Kottanadu, Mezhuvelil, Naranganam, Pandalam, Pandalam Thekkekkara, Ranni, Thannithodu, Thottapuzhaserry, Vallicode, Vechuchira	14 (28%)
Medium (25-50%)	Chittar, Erathu, Eraviperoor, Kadampnadu, Kalanjor, Konni, Kozhenchery, Kulanada, Mallappuzhaserry, Mylapra, Naranamoozhi, Nedumbram, Ranni Angadi, Ranni Pazhavangadi, Seethathodu, Thiruvalla M C, Thumpamon, Vadaserrykkara	18 (36%)
High (50-75%)	Anicaud, Aranmula, Ayiroor, Chennneerkara, Cherukole, Enadimangalam, Ezhumatoor, Kaviyoor, Kottangal, Kunnathanam, Mallappally, Omallur, Pallickal, Pathanamthitta M C, Pramadam	15 (30%)
Very high (75-100%)	Aruvappulam, Kadapra, Koipram	3 (6%)

It is evident from Table 3 that, 36 per cent of panchayats in Pathanamthitta are having medium soil fertility and around 30 per cent in both high and low groups of fertility. The three panchayats, namely Aruvappulam, Kadapra and Koipram possess very high soil fertility. The parameters P and Ca were found to be the most significant parameters contributed to fertility disparities among the panchayats in Pathanamthitta. In Pathanamthitta almost all the parameters were sufficiently available in most of the panchayats. This may lead to good soil fertility condition of Pathanamthitta district. Based on this classification, grouping of panchayats were pictorially represented in the district map of Pathanamthitta and is given in Fig. 2

**Fig 2:** Map depicting soil fertility status of panchayats in Pathanamthitta

Conclusion

This study implies the relatively good soil fertility of the district under study. With regard to the soil fertility index, Aruvappulam panchayat in Pathanamthitta district shows higher soil fertility and Thottapuzhaserry panchayat is poor in all among them. Physiographically, the district is divided into coastal plain, mid land region and hill ranges with major area come under hill ranges and is thickly forested. Major soil type in Pathanamthitta is forest loam which is formed as a result of weathering of country rock under forest cover (KSPB, 2013) [12]. This forest soils are rich in organic matter content with good water retention capacity. This influence positively to the availability various plant nutrients in the soil. This may be the reason for observed good soil fertility of Pathanamthitta district. Along with this adequate fertility management practices have to be adopted to maintain the district agriculturally productive. PCA as a multivariate technique is very useful in reducing the dimension

of large data set and also in construction of index in order to measure the latent variables.

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Conflict of Interest

No conflict of interest

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