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Manoj Kumar
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

RK Sahni
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Mukesh Kumar
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

V Bhushan Babu
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

HS Pandey
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Corresponding Author:
Manoj Kumar
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

Crop productivity index of Madhya Pradesh: An application of principal components analysis

Manoj Kumar, RK Sahni, Mukesh Kumar, V Bhushan Babu and HS Pandey

Abstract
The objective of this paper is to construct Crop Productivity Index (CPI) to rank different districts of the Madhya Pradesh, India. The CPI ratings provide a relative ranking based on their potential for crop production. The secondary data on productivity of Rice, Wheat, Gram, Groundnut, Sugarcane and Urd of 51 districts of Madhya Pradesh for the year 2015-16 were taken and analysed. The multidimensional scaling of the productivity of many different crops has been done using Principal Component Analysis (PCA). The ranking and categorization of districts of Madhya Pradesh have been done using constructed composite index namely Crop Productivity Index. It was found that Morena district ranked first followed by Sehore and Chindwara in terms of high productivity and the districts like Sagar, Chhatarpu and Dindori were placed in a group with low productivity of crops under study.

Keywords: Crop productivity index, multidimensional scaling, principal component analysis

Introduction
Madhya Pradesh is located at the central part of India as its name suggests in Hindi language. It is the second largest state of India by area and sixth largest state by population. This state comprises 11 agro-climatic zones with diverse soil and climatic condition. Due to this, a wide range of crops are cultivated with diversified cropping pattern. Madhya Pradesh comes in the category of top states in producing wheat, pulses and oilseeds. In 2016-17, the net sown area was 152.28 lakh hectares out of which the irrigated area was 98.75 lakh hectares. There was 139% increase in the irrigated area as compared to 2000-2001 (41.35 lakh hectare). Madhya Pradesh has received Krishi Karman award many times for wheat production. The increase in wheat production was due to tremendous increase in irrigated area, farm power availability and judicious use of organic and inorganic fertilizer.
Multidimensional scaling has been done by many authors using different approaches. The Analytic Hierarchy Process (AHP) is one of the popular approaches that are being used in many areas. The AHP was introduced in late 1970s which is purely based on expert judgment. The experts of relevant field give their opinion/priorities to several alternatives. This methodology is subjective in nature as it is based on expert's judgment. Parker (1991) [8] constructed environmental problem index using public opinion as a weighting technique. The AHP technique has been used by Ercot and Moran (1991) [2] in ranking of municipal landfill potential sites for City of Edmonton, Alberta, Canada. A technique for construction of composite index was proposed by Narain *et al.* (1991) [7] and they constructed a composite index of development. This technique is affected by the problem of multicollinearity. Ahmad *et al.* (2003) [1] identified potential agro-forestry areas by using Objective Analytic Hierarchy Process (OAHP). Kumar *et al.* (2012) [3] proposed empirical method for sensitivity analysis of composite index using variance-based technique.
The techniques used so far to construct composite index is subjective in nature or/ and influenced by the problem of multicollinearity. Kumar *et al.* (2013) [4] proposed and used Principal Component Analysis (PCA) in construction of composite index to overcome the problem of multicollinearity and developed Agriculture Development Index of Bihar State, India. Kumar *et al.* (2015) [5] constructed flower production index of the districts of West Bengal and classified the districts on the basis of flower production index. Majumder *et al.* (2017) [6] constructed cash crop index and ranked the Indian states on the basis of constructed index.

There are 11 agro-climatic zones in Madhya Pradesh with different soil type and climatic conditions, due to this, a wide range of crops are cultivated. Madhya Pradesh occupies position in the category of top most states for producing wheat, pulses and oilseeds. Also, Madhya Pradesh received Krishi Karman Award fifth time continuously. The achievement has been accomplished with increase in irrigated area, hard work of farmers and extension workers. There is a need to identify and focus on the under developed districts regarding agricultural production. Thus, in the present paper, Crop Productivity Index (CPI) has been constructed using PCA with available indicators for 51 districts of Madhya Pradesh, India to rank and categorized the districts of this state.

Materials and Methods

The district-wise data on productivity of crops were collected online from the secondary source available with Directorate of Economics and Statistics, Govt. of India, for the year 2015-16. The data on productivity of Rice, Wheat, Gram, Groundnut, Sugarcane and Urd were taken and analyzed. The methodology developed by Kumar *et al.* (2013) [4] was utilized in construction of composite index. The procedure has been described as under.

The Maximum Likelihood Estimate (M.L.E.) of variance-covariance matrix (Σ) of the data set was estimated as

$$\hat{\Sigma} = \frac{1}{n}\sum_{i=1}^{n}\left(\underline{X}_i - \overline{\underline{X}}\right)\left(\underline{X}_i - \overline{\underline{X}}\right)' \quad \ldots (1)$$

Where,

$$\underline{X} = \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_q \end{bmatrix}$$

Where, q is the number of variables, $\overline{\underline{X}} = \frac{1}{n}\sum_{i=1}^{n}\underline{X}_i$ and n is total number of districts.

The Correlation Matrix (CM) was obtained using above variance-covariance matrix as

$$CM = \left(\sqrt{V}\right)^{-1}\hat{\Sigma}\left(\sqrt{V}\right)^{-1} \quad \ldots (2)$$

Where,

V: Diagonal matrix obtained from variance-covariance matrix

$\hat{\Sigma}$: M. L.E. of variance-covariance matrix

Now the principal components were obtained using eigen vectors of the estimated correlation matrix and standardized values of variables. The principal components were obtained as given below.

$$P_1 = a_{11}Z_1 + a_{12}Z_2 + \ldots + a_{1q}Z_q$$
$$P_2 = a_{21}Z_1 + a_{22}Z_2 + \ldots + a_{2q}Z_q$$
$$.$$
$$.$$
$$.$$
$$P_q = a_{q1}Z_1 + a_{q2}Z_2 + \ldots + a_{qq}Z_q$$

Where,

P_q: q[th] principal components

Z_q: standardized values of q[th] variable

a_{kq}: element belonging to k[th] eigenvector and for q[th] variable, k=1,2, …,q; q=1,2, …,q

The next step was to construct composite index using the obtained eigen values of variables and principal components as given below

$$CI_i = \frac{\lambda_1 P_1 + \lambda_2 P_2 + \ldots + \lambda_q P_q}{\sum_{j=1}^{q}\lambda_j} \quad \ldots (3)$$

Where,

CI_i: composite index for i[th] district,

λ_j: Eigen values,

P_q: q[th] principal components, i=1,2, …,n; j=1,2, …,q.

Lastly, the constructed composite index of each district was normalized by using the following formula to convert the index value between 0 and 1.

$$CI_{ni} = \frac{CI_i - \min(CI)}{\max(CI) - \min(CI)} \quad \ldots (4)$$

Where,

CI_{ni}: Normalized value of composite index of i[th] district

min (CI): Minimum value of composite index

max (CI): Maximum value of composite index

Results and Discussion

The data analysis was performed using SAS 9.3 package (SAS Institute India Private Limited, Mumbai, India), a software for statistical analysis. The productivity (tonnes/hectare) of different crops with Standard Error (SE) like Gram (1.08 ± 0.02), Wheat (2.96 ± 0.11), Groundnut (0.77 ± 0.04), Rice (1.36 ± 0.15), Sugarcane (2.64 ± 0.15) and Urd (0.53 ± 0.02) were evaluated. The productivity of crops with error bar has been presented in Fig. 1.

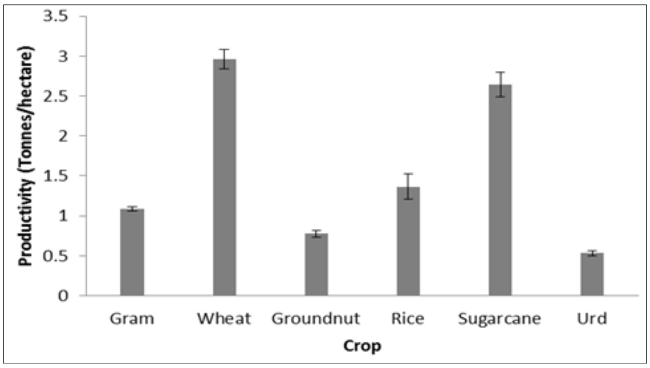

Fig 1: Productivity of crop with Standard Error (SE)

The PRINCOMP procure was used to analyse the data. The evaluated correlation matrix is presented in Table-1. The correlation between productivity of (GRAM, WHEAT), (GRAM, SCANE) and (SCANE, URD), was found significant at p value 0.05. There was negative correlation between productivity of sugarcane and urad because urd is cultivated in *kharif* season and sugarcane is a long duration crop. The correlation between remaining variable were not found significant at p value 0.05.

Table 1: Correlation matrix for productivity of different crops

	GRAM	WHEAT	GNUT	RICE	SCANE	URD
GRAM	1	0.36*	0.08	0.15	0.30*	-0.05
WHEAT		1	0.06	0.21	0.19	-0.14
GNUT			1	-0.17	0.16	-0.07
RICE				1	0.06	0.15
SCANE					1	-0.33*
URD						1

Note: The values indicated by * is significant at p value 0.05

The Eigen values and Eigen vectors of the above correlation matrix were obtained using PRINCOMP procedure. The Eigen values and Eigen vectors are presented in Table 2 & Table 3, respectively. It can be observed from the table that only first four principal component accounts for more than 80% variability in the dataset are present. The sensitivity of constructed composite index can also be judged by observing the components of eigenvectors. The variables/indicators having highest component in first Eigen vector influences maximum to the Composite Index (CI) that means the CI is highly sensitive to those indicators. Thus, it was concluded that the constructed composite index is highly sensitive to productivity of Sugarcane followed by Gram.

Table 2: Eigen values

Eigen values of the Covariance Matrix			
	Eigen value	Explained variation	Cumulative
1	1.78	0.29	0.29
2	1.33	0.22	0.52
3	0.94	0.15	0.67
4	0.74	0.12	0.80
5	0.6	0.11	0.91
6	0.48	0.08	1

Table 3: Eigen vectors

		Eigen vectors				
	PC1	PC2	PC3	PC4	PC5	PC6
GRAM	0.52	0.21	0.25	-0.16	-0.63	-0.42
WHEAT	0.50	0.23	0.07	-0.58	0.40	0.40
GNUT	0.20	-0.45	0.72	0.20	0.37	-0.19
RICE	0.17	0.65	-0.08	0.49	0.42	-0.32
SCANE	0.53	-0.20	-0.18	0.56	-0.20	0.52
URD	-0.34	0.45	0.59	0.14	-0.25	0.48

Note: PC indicates the Principal Component.

The construction of Crop Productivity Index (CPI) was performed using the methodology proposed by Kumar *et al.* (2013) [4]. The composite index value for every district along with their rank is presented in Table 4. The districts were identified and grouped into three categories High, Moderate and Low on the basis of constructed CPI. The CPI values greater than or equal to 75th percentile were grouped as high productivity zone, the districts having CPI values less than 75th percentile but greater than 25th percentile were identified as moderate productivity zone and the districts having CPI values less than 25th percentile value were identified as low productivity zone. The 25th percentile and 75th percentile value were found to be 0.227 and 0.554 respectively.

Table 4: District wise crop productivity index (CPI) along with their rank

S No	Districts	CPI	Category	S No	Districts	CPI	Category
1	Morena	1.000	High	27	Khandwa	0.425	Moderate
2	Sehore	0.992	High	28	Neemuch	0.417	Moderate
3	Chhindwara	0.975	High	29	Rajgarh	0.410	Moderate
4	Gwalior	0.852	High	30	Damoh	0.355	Moderate
5	Hoshangabad	0.837	High	31	Katni	0.351	Moderate
6	Sheopur	0.802	High	32	Agar Malwa	0.349	Moderate
7	Narsinghpur	0.776	High	33	Dhar	0.338	Moderate
8	Guna	0.736	High	34	Indore	0.309	Moderate
9	Bhind	0.701	High	35	Shajapur	0.289	Moderate
10	Datia	0.677	High	36	Balaghat	0.273	Moderate
11	Burhanpur	0.577	High	37	Dewas	0.263	Moderate
12	Bhopal	0.541	Moderate	38	Mandsaur	0.242	Moderate
13	Alirajpur	0.539	Moderate	39	Ujjain	0.213	Low
14	Ashoknagar	0.534	Moderate	40	Jhabua	0.210	Low
15	Khargone	0.533	Moderate	41	Seoni	0.200	Low
16	Harda	0.532	Moderate	42	Umaria	0.189	Low
17	Barwani	0.530	Moderate	43	Tikamgarh	0.174	Low
18	Raisen	0.523	Moderate	44	Panna	0.133	Low
19	Shivpuri	0.508	Moderate	45	Rewa	0.132	Low
20	Shahdol	0.508	Moderate	46	Sidhi	0.104	Low
21	Betul	0.493	Moderate	47	Anuppur	0.101	Low
22	Vidisha	0.465	Moderate	48	Ratlam	0.097	Low
23	Mandla	0.465	Moderate	49	Sagar	0.087	Low
24	Jabalpur	0.457	Moderate	50	Chhatarpur	0.053	Low
25	Satna	0.449	Moderate	51	Dindori	0.000	Low
26	Singrauli	0.433	Moderate				

Conclusion

The secondary data on productivity of Rice, Wheat, Gram, Groundnut, Sugarcane and Urd of 51 districts of Madhya Pradesh for the year 2015-16 were analyzed and it was observed that correlation between productivity of Gram with Wheat and Sugarcane was significant at p value 0.05. The correlation between Sugarcane and Urd was also significant. The Crop Productivity Index (CPI) for each district was constructed to identify and group them into three categories High, Moderate and Low on the basis of constructed CPI. The categorization of districts was done on the basis of percentile value of CPI. The 25th percentile and 75th percentile value were found to be 0.227 and 0.554 respectively. The Morena district ranked first followed by Sehore and Chindwara and the districts like Sagar, Chhatarpu and Dindori were grouped into category with low in productivity of crops under study.

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