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Soil suitability evaluation for cotton using analytical hierarchic process

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Abstract
The aim of this study was to determine soil suitability for cotton cultivation in semi-arid region of Hinganghat tehsil, Wardha district, Maharashtra, India where the probability of crop failure for average yield of cotton is reported highest and the farmers have been experiencing distress situation over the last two decades. The ‘‘Analytic Hierarchy Process (AHP)’’ method, commonly used in soil suitability analysis, was used in this study. AHP is additive weighing model where the weights for the suitability criteria and the scores of each alternative are calculated by experts’ pair wise comparisons. Six soil series reported in the tehsil namely, Bothali, Chanakpur, Waigaon, Hewan, Karla, and Lasanpur with varying properties were selected for analysis. Soil organic matter, soil depth, soil drainage condition, and clay with associated properties were selected as suitability criteria. The weights of the parameters selected were found to be in order: depth (56%), clay properties (26%), organic carbon (12%), and drainage (6%). The result indicates that the suitability of the soil series for cotton cultivation decreases in order from Hewan, Bothali, Lasanpur, waigaon, Karla, and Chanakpur.

Keywords: Analytical hierarchic process (AHP), soil site suitability, cotton, YAML

Introduction
Crop and soil suitability analysis is suggested as a prerequisite to achieve optimum utilization of available land for agricultural production (Sys, 1985; Van Ranst *et al*. 1996) [34, 35]. This analysis involves integration of various criteria which can be well achieved by multi-criteria evaluation techniques (Eastman, 1999; Silva and Blanco, 2003; Prakash, 2003; Malczewski, 2006; Ying *et al*. 2007; Cinelli *et al*. 2014) [7, 32, 19, 15, 38, 6]. It has successfully been applied for suitability analysis for different objectives in agriculture (Mendoza and Prabhu, 2003; Feizizadeha and Blaschke, 2012; Romano *et al*. 2015) [17, 8, 23]. Mendoza and Martins (2006) [16], Balteiro and Romero (2008) [4] and Ananda and Herath (2009) [2] have reviewed different methods of MCDA applied to forest and other natural resource management critically in terms of the nature of the models, their inherent strengths and limitations.

Out of many approaches in MCDA, the additive weighting methods have been by far the most popular (Silva and Blanco, 2003; Ayalew *et al*. 2005; Walke *et al*. 2012; Kumar *et al*. 2015, 2017) [32, 3, 36, 10]. The method is easy-to-understand and intuitively appealing to decision makers (Malczewski, 2000) [13]. In this method, the decision maker assigns weights of “relative importance" to each criterion and scores to each alternative under each criterion. A total score is then obtained for each alternative by multiplying the importance weight assigned for each criterion by the score value given to the alternative on that criterion, and summing the products over all criteria (Malczewski, 2000; Walke *et al*. 2012; Zolekar and Bhagat, 2015; Kumar *et al*. 2015, 2017) [13, 36, 39, 10]. The alternative with maximum overall score is selected as the best alternative.

The Analytical Hierarchy Process (AHP), introduced by Thomas Saaty (1980) [24] has emerged as a popular decision making technique for solving multi-criteria problems (Ramanathan and Ganesh 1995; Ying *et al*. 2007; Feizizadeha and Blaschke, 2012; Akıncı *et al*. 2013; Romano *et al*. 2015; Zolekar and Bhagat, 2015) [22, 38, 8, 1, 23, 39] which is based on the additive weighting model (Basnet *et al*. 2001; Malczewski, 1999, 2004) [5, 12, 14]. The AHP generates weights and the scores according to the experts’ pair-wise comparisons. In addition, the AHP checks the consistency of the decision maker’s evaluations, thus reducing the bias in the decision making process.

It is a practical decision analysis method which can deal with mixed sets of data, quantitative and qualitative (Malczewski, 2004, 2006; Mendoza and Martins, 2006; Balteiro and Romero, 2008; Ananda and Herath, 2009; Wu *et al*. 2011; Zolekar and Bhagat, 2015) [14, 15, 16, 4, 2, 37, 39]. The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain. The comforts and difficulties in using AHP have been discussed by many researchers (Malczewski, 1999; Ramanathan, 2001; Prakash, 2003) [12, 21, 19]. The AHP is a very flexible and powerful tool because the weights and scores, and therefore, the final ranking are obtained on the basis of the pair-wise relative evaluations of both the criteria and the alternatives provided by the user. The computations made by the AHP are always guided by the decision maker's experience. In addition, the AHP is simple because there is no need of building a complex expert system with the decision maker's knowledge embedded in it.

The present attempt is made to evaluate the suitability of the soils of Hinganghat tehsil-a major cotton growing area in Wardha district, for cotton cultivation using AHP.

Materials and Method

Study Area

Hinganghat is a tehsil in Wardha district located in the Vidarbha region of Maharashtra state and lies between 20^0 18′ to 20^0 42′ North latitudes and 78^0 32′ to 78^0 57′ east longitudes (Fig 1). The tehsil covers an area of 874.65 sq. km. The climate of area is characterized by hot summers and a general dryness throughout the year except during the south-west monsoon. The average annual rainfall is 1090.3 mm, out of which 87 percent is received during June to September. The major land use category in the tehsil is agriculture. *Kharif* and *rabi* are the two agricultural seasons. The major crops grown in *kharif* season are cotton, soybean, and pigeon pea as intercropping in both the crops. In the *rabi s*eason, wheat and gram are cultivated depending upon availability of water.

The tehsil falls under the physiographic unit of Wardha-Hinganghat plains, fertile riverine plains draining and sloping gently southwards towards the Wardha River. Elevation ranges from 155 to 261 m above mean sea level. The tehsil is having maximum area under level to nearly level and very gently sloping lands (Sharma *et al*. 2005) [30].

Soils of the study area

Soil database has been taken from reconnaissance survey maps of Wardha district (Shrama *et al*. 2008) [31] at 1:50,000 scale. The soil resource database of the district was prepared by reconnaissance soil survey on 1:50000 scale based on fourteen land forms delineated in the district. The soils were identified by traversing representative areas and applying information to like areas. Some additional observations and transects were made for verification. The profiles at intervals of 3 to 6 km or shorter intervals depending upon the soil heterogeneity were studied. The morphological properties of soil profiles were recorded and classified as per USDA soil taxonomy (Soil Survey Staff, 1998) [33]. Six soil series are identified in the tehsil namely, Bothali, Chanakpur, Waigaon, Hewan, Karla, and Lasanpur. Taxonomically these soils come under Entisols (Chanakpur), Vertisols (Bothali, Hewan), and Inceptisols (Waigaon, Karla and Lasanpur). The detailed properties are shown in table 1.

Analyzing the soil type in the tehsil, it is found that black soil with high clay percentage is the predominant soil type. Out of six soil series, three (Bothali, Hewan, and Lasanpur) are deep and high in organic carbon which facilitates good crop growth. Soils are high in calcium and magnesium carbonate which have adverse implications for crop growth. Phosphorous reacts with calcium and magnesium carbonate and gets fixed as calcium phosphate and magnesium phosphates which are highly immobile phosphorous compounds. This results in unavailability of phosphorous, a major macronutrient to the plants. However, the cation-exchange capacity (CEC) of these soils is high which makes them more responsive to fertilizer application and nutrient management. The higher Exchangeable Magnesium Percentage (EMP) of the soil series Bothali makes these soils less conductive to water and restricts root growth. Other two soil series namely, Waigaon and Karla are moderately shallow and the organic carbon content is in the low-to medium category. Low organic carbon content is indicative of low level of nitrogen in the soil. These soils are very gently sloping but are subjected to severe erosion, which is the dominant limiting factor for plant growth. These soils are clayey and well drained and have slow permeability. These soils are considered to be of average productive potential. However, the CEC of the soil is high, indicating that the soil would respond well to fertilizer application and nutrient management. The soil series Chanakpur is very shallow with least clay content among the six. The medium organic carbon content, least CEC and Base Saturation (BS) makes it less fertile. The drainage and erosion are excessive for this soil series.

Soil Suitability Ranking

In the research, based on the Delphi expert advice system, the AHP method was applied to determine the weights of each criterion and the scores of each alternative soil series to rank them for cotton suitability. AHP consists of four steps. One, define objective, criteria or factors.

Table 1: Characteristics of the soils occurring in the tehsil

Property	Bothali	Chanakpur	Waigaon	Hewan	Karla	Lasanpur
Depth	128	25	64	105	64	113
Drainage	Moderately Well	Excessive	Well	Moderately Well	Well	Moderately Well
AWC	17.86	12.5	12.1	14.24	15.59	14.04
Clay	63.85	35	64.53	72.22	60.63	57.36
OC	0.75	0.73	0.61	0.96	0.44	0.83
EC	0.28	0.42	0.31	0.18	0.42	0.26
pH	7.86	7.9	7.8	8.04	7.94	7.66
CEC	59.55	47	54.9	57.77	53.41	55.25
BS	137.16	96.3	99.3	99.64	102.77	99.6
ESP	1.08	0.93	0.88	0.79	1.01	1.08
EMP	34.89	9.60	14.34	7.11	12.00	15.11

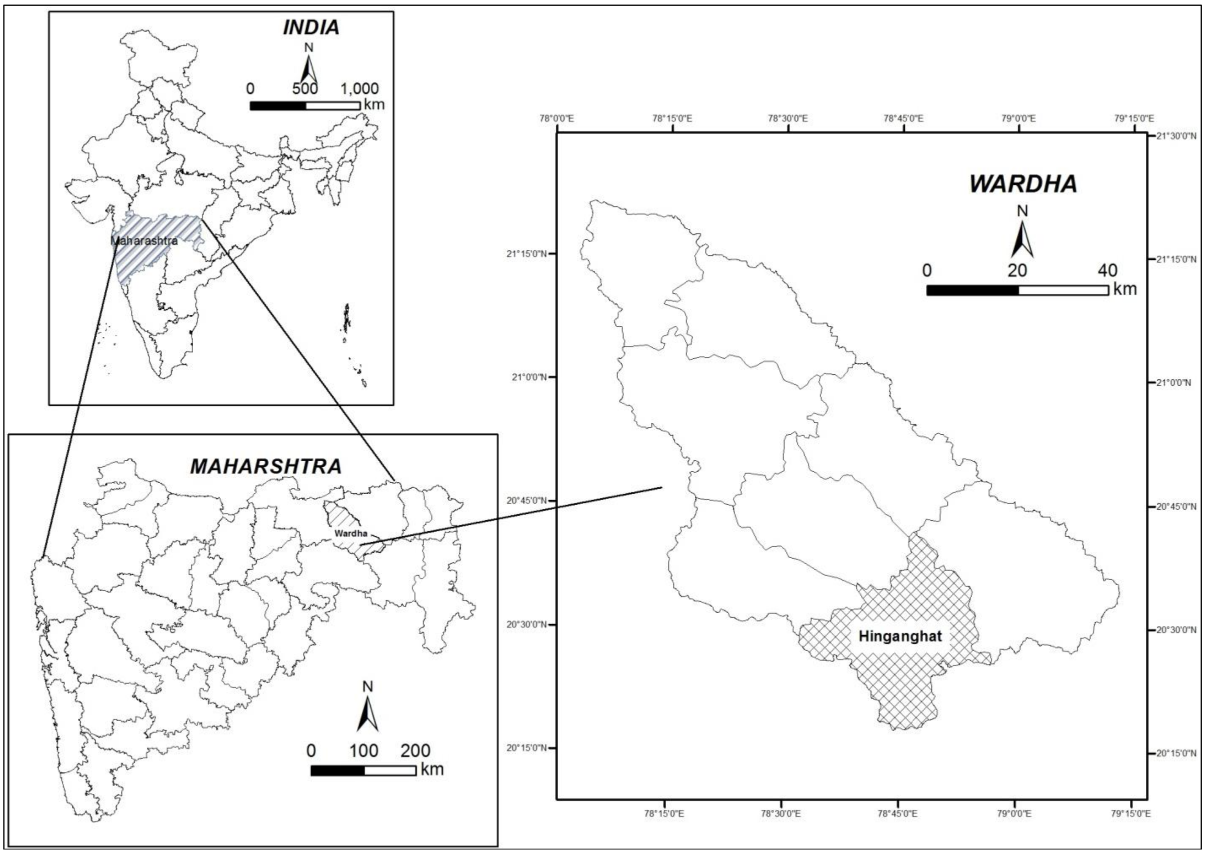

Fig 1: Study area

That influence the objective and structure these factors into levels and sublevels. Two, use paired comparisons of each factor with respect to each other that forms a comparison matrix with calculated weights, ranked eigenvalues, and consistency measures. Three, use the paired comparisons for alternatives under each factor and calculate scores and consistency measures. Four, addition of products of weights of the factors and scores of alternatives to synthesize the ranks of alternatives (Saaty, 1980, 1987, 2000; Ramanathan and Ganesh, 1995) [24, 25, 26, 22].

The objective, factors and the comparison matrices were defined in 'Yet another Mark-up Language' (YAML) (http://www.yaml.org/) (supplement 1) and analyzed in AHP module (http://github.com/gluc/ahp/) of R (R Core Team, 2016) [20] to generate the hierarchic structure, weights and scores, and the rank of the soils. The detailed analytic process was as follows:

Establishment of the hierarchic structure

Based on the expert advice, the evaluation system was divided into three levels denoting Objective Layer, Factors Layer and Alternatives Layer. The top layer i.e., objective of the study was to rank soil suitability for cotton. The second layer was comprised of the factors identified for suitability of soils for cotton. The third layer was of the candidate soils. Six cotton cultivating soil series namely, Bothali, Chanakpur, Waigaon, Hewan, Karla, and Lasanpur occurring in the tehsil with varying properties were selected for the study.

Establishment of comparison matrices

Each layer in the hierarchic structure was compared in pairwise comparisons based on AHP preference scale (Table 2) to form the comparison matrices. The Relative importance of each factor were analyzed by *Delphi* method, also called *Expert Judgment System*. In this research, we invited experts with natural resource management backgrounds to give the relative importance of each factor, respectively, then analyzed all the opinions, and finally, gained the rank of relative importance for each factor. Similar exercise was done for each of the factors for getting scores for each candidate soil.

Table 2: Preference Scale (Source: [39])

AHP Scale of Importance for comparison pair	Numeric Rating	Reciprocal
Extremely Importance	9	1/9
Very strong to extremely	8	1/8
Very strong importance	7	1/7
Strongly to very strong	6	1/6
Strong Importance	5	1/5
Moderately to strong	4	1/4
Moderate importance	3	1/3
Equally to Moderately	2	1/2
Equal importance	1	1

Calculation of weights and scores

The weights and scores are calculated from the pair-wise comparison matrices undertaking an eigenvalues and eigenvectors calculation using R (R Core Team, 2016) [20]. The eigenvector corresponding to the largest eigenvalue of the matrix (principal eigenvector) provides the relative priorities of the factors (Saaty, 1980, 2001; Ramanathan, 2001) [24, 27, 21]. The components of the eigenvector sum to unity. Thus, a vector of weights is obtained, which reflects the relative importance of the various factors from the matrix of paired comparisons.

To keep the consistency of the judgment matrix, its consistency should be tested. In AHP, an index of consistency, known as the consistency ratio (CR), is used to indicate the probability that the matrix judgment were randomly generated (Saaty, 1980) [24].

$$CR = CI/RI \quad (1)$$

Where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty (1980) [24] (table 3) and CI is the consistency index and can be expressed as

$$CI = (\lambda_{max} - n)/(n-1) \quad (2)$$

Where λ_{max} is the largest or principal eigenvalue of the matrix and can be easily calculated from the matrix, and n is the order of the matrix. When the matrix has a complete consistency, CI = 0. The bigger CI is, the worse consistency the matrix had (Saaty, 1980, 1987) [24, 25]

When CR was less than 0.10, the matrix had a reasonable consistency. Otherwise the matrix should be changed. The calculated results of weight would be accepted when the consistency ratio was satisfactory (Saaty 1980, 2003; Ying *et al*. 2007). [24, 28, 38]

Table 3: Random inconsistency indices (RI) for N=10 (Source: [24])

N	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Integration of weights and ranking

A weighted additive approach was followed using calculated weights and scores to rank the soils for suitability for cotton. The overall score of each alternative was calculated as

$$SR = \sum_{j=1}^{n} W_j S_{ij} \quad (3)$$

Where, SR is suitability rank of the soil, n is the number of factors and W_j is the weight of j^{th} factor, and S_{ij} is the scores of the i^{th} alternative against the j^{th} factor.

Results and Discussion

Hierarchic Structure

The hierarchic structure generated by R- AHP is shown in figure 2. The top level of the diagram shows the overall goal (objective) of the hierarchy, "Soil Suitability Rank for Cotton". The second level lists the attributes each of the third-tier candidates (soils) have. Soil organic matter, soil depth, soil drainage condition, and clay properties such as content, cations, Exchangeable Sodium Percentage (ESP), Exchangeable Magnesium Percentage (EMP), and Base Saturation (BS) were selected as the factors for soil suitability evaluation for cotton based on experts' opinion. Out of the four factors, the soil drainage condition is qualitative and 'clay properties' is a bundle of parameters in one factor.

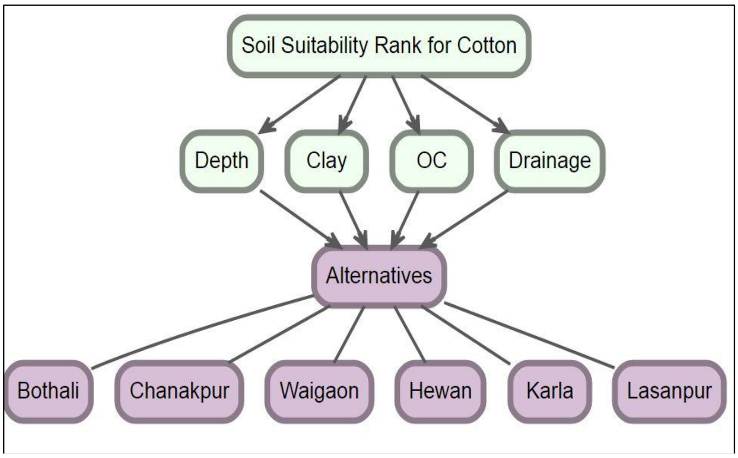

Fig 2: The hierarchic structure of the study

Comparison Matrices

The comparison matrices were established based on the expert opinions. For the comparison of factors (Table 4), the conclusions were:

- The deep, friable, well-drained soils with good organic matter content are ideal for cotton cultivation in the area. The depth of the soils is varying most - from 25 cm to 128 cm in the study area and considered most crucial for cotton cultivation.
- The clay properties including clay type, clay content, base saturation, CEC, ESP, and EMP were preferred over organic carbon and drainage conditions.
- Comparing with depth, clay properties, and organic carbon, drainage is less important. But it could not be ignored, as cotton crop is sensitive to water logging and thus prefers well- drained soils (Malawath *et al*. 2014; Naidu *et al*. 2006) [11, 18].

Table 4: Comparison matrix for factors

	Depth	**Drainage**	**Clay**	**OC**
Depth	1	7	3	5
Drainage	1/7	1	1/5	1/3
Clay	1/3	5	1	3
OC	1/5	3	1/3	1

The comparison matrices for the alternatives under each factor are shown in table 5. In case of the factor depth, deep soils were preferred over the shallow soils. Under the factor clay properties, the preference is given in the order: Hewan> Waigaon = Karla> Lasanpur> Bothali > Chanakpur. The soil series Hewan was suggested to be preferred over others owing to have high clay content, CEC, least ESP and EMP. The series Waigaon and Karla were found to have similar clay content, CEC, ESP and EMP and were assigned same weights. The series Bothali having similar percentage of clay was given less importance than Waigaon, Karla and Lasanpur due to high EMP. The series Chanakpur was given least weight due to least clay and high sand content and least CEC. For the factor organic carbon, higher weight was given to the soil having high organic carbon content. For drainage conditions of soils, well drained soils were given higher weights followed by moderately well drained and excessively drained.

Table 5: Comparison matrix for alternatives under each factor

Depth	**Bothali**	**Chanakpur**	**Waigaon**	**Hewan**	**Karla**	**Lasanpur**
Bothali	1	7	5	3	5	2
Chanakpur	1/7	1	1/5	1/7	1/5	1/7
Waigaon	1/5	5	1	1/3	1	1/3
Hewan	1/3	7	3	1	3	1
Karla	1/5	5	1	1/3	1	1/3
Lasanpur	1/2	7	3	1	3	1
Clay						
Bothali	1	5	1/3	1/4	1/3	1/2
Chanakpur	1/5	1	1/7	1/8	1/7	1/5
Waigaon	3	7	1	1/3	1	2
Hewan	4	8	3	1	2	3
Karla	3	7	1	1/2	1	2
Lasanpur	2	5	1/2	1/3	1/2	1
Organic Carbon						
Bothali	1	1	3	1/3	5	1/2
Chanakpur	1	1	3	1/3	5	1/2
Waigaon	1/3	1/3	1	1/6	4	1/5
Hewan	3	3	6	1	7	2
Karla	1/5	1/5	1/4	1/7	1	1/8
Lasanpur	2	2	5	1/2	8	1
Drainage						
Bothali	1	3	1/3	1	1/3	1
Chanakpur	1/3	1	1/5	1/3	1/5	1/3
Waigaon	3	5	1	3	1	3
Hewan	1	3	1/3	1	1/3	1
Karla	3	5	1	3	1	3
Lasanpur	1	3	1/3	1	1/3	1

Weights and Scores

The weights for the factors (figure 3) and the scores for the alternatives (figure 4) were calculated from the comparison matrices. The weight for factor depth was highest (56.5%) followed by clay properties (26.2%), organic carbon (11.8%), and drainage (5.5%). The consistency of the comparison matrix was 4.3%, which suggests that the matrix for the factors was consistent. The consistencies of the matrices for alternatives were also within acceptable limit. The series Bothali scored maximum for the factor depth. For factors clay properties and organic carbon, the series Hewan scored the highest. For drainage, Waigon and Karla scored highest- both being well drained soils.

	Priority	Bothali	Chanakpur	Waigaon	Hewan	Karla	Lasanpur	Inconsistency
Soil Suitability Rank for Cotton	100.0%							4.3%
Depth	56.5%	33.6%	2.9%	8.7%	21.8%	8.7%	24.5%	3.3%
Clay	26.2%	8.1%	3.4%	17.7%	42.1%	19.2%	9.5%	4.6%
OC	11.8%	14.1%	14.1%	6.3%	37.3%	3.0%	25.2%	3.1%
Drainage	5.5%	11.3%	4.7%	30.8%	11.3%	30.8%	11.3%	0.9%

Fig 3: Identified weights for criteria chosen for soil suitability evaluation

	Weight	Hewan	Bothali	Lasanpur	Karla	Waigaon	Chanakpur	Inconsistency
Soil Suitability Rank for Cotton	100.0%	28.3%	23.4%	19.9%	12.0%	12.0%	4.4%	4.3%
Depth	56.5%	12.3%	19.0%	13.8%	4.9%	4.9%	1.6%	3.3%
Clay	26.2%	11.0%	2.1%	2.5%	5.0%	4.6%	0.9%	4.6%
OC	11.8%	4.4%	1.7%	3.0%	0.4%	0.7%	1.7%	3.1%
Drainage	5.5%	0.6%	0.6%	0.6%	1.7%	1.7%	0.3%	0.9%

Fig 4

Soil suitability and ranking
In AHP, a weighted additive method is applied to rank the alternatives according to their suitability for cotton. The ranks of the six soil series are shown in figure 4. The series Hewan got the highest rank (28.3%) followed closely by Bothali (23.4%) and Lasanpur (19.9%). The Hewan soil was found to be best for cultivation of cotton in the area. The latter two series were moderately fit for cotton. The next two soil series namely, Waigaon and Karla were ranked fourth and fifth, respectively and may be marginally suitable for cotton cultivation. The Chanakpur soil series was found to be of last rank (4.4%) and are least suitable for cotton cultivation in the study area.

Conclusions
In general, the results obtained from this study indicate that:
- The analytical hierarchy process is a powerful tool for ranking soils based on multiple factors for their suitability for a considered land use. Specified soil suitability ranks help decision makers for defining effective management plan for each soil series considering its suitability rank.
- The depth of the soils is identified as the most important factor in the area for cotton cultivation followed by clay, organic carbon and drainage.
- Among the soil series occurring in the study area, Hewan series ranks first, followed by Bothali and Lasanpur. The allocation of land for cotton cultivation should be planned accordingly.
- The soil series Waigaon and Karla were ranked fourth and fifth, respectively. These soils may be cultivated for cotton with proper management and supervision.
- The soil series Chanakpur was ranked last and have unfavorable soil properties for growing cotton.

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