Eco. Env. & Cons. 29 (April Suppl. Issue) : 2023; pp. (S454-S463)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i02s.074

Assessment of soil fertility for wheat using combined Fuzzy and AHP techniques in Udham Singh Nagar of Uttarakhand, India

Sudheer Kumar[1], Prem Kumar Bharteey[2]*, Lata Vishnoi[3], Sumit Rai[4], Supriya Pandey[4], Bipul Deka[5], Marami Dutta[6], Ashok Kumar[7], Sanjib Ranjan Borah[8], Ayush Bahuguna[2], Nidhi Luthra[2] and Sudhir Pal[2]

[1]Department of Agricultural Engineering, C.C.R. (P.G.) College, Muzaffarnagar 251 001, U.P., India
[2]Department of Agricultural Chemistry, C.C.R. (P.G.) College, Muzaffarnagar 251 001, U.P., India
[3]India Meteorological Department, New Delhi, India
[4]Center for Environment Assessment and Climate Change, GB Pant National Institute of Himalayan Environment, Kosi-Katarmal, Almora 263 643, Uttrakhand, India
[5]AICRP on IWM, Assam Agricultural University, Jorhat 785 013, Assam, India
[6]Department of Soil Science, Assam Agricultural University, Jorhat 785013, Assam, India
[7]Department of Agricultural Chemistry, P.G. College, Ghazipur, 233 001, Uttar Pradesh, India
[8]Regional Agricultural Research Station, Assam Agricultural University, Titabar 785 630, Assam, India

(Received 24 November, 2022; Accepted 17 January, 2023)

ABSTRACT

Assessing soil fertility is crucial for developing effective soil management strategies that can enhance soil health, increase crop productivity, and promote sustainable agricultural practices. The current study was conducted to assess the soil fertility index and, to prepare a soil fertility zonation map using combine fuzzy and analytical hierarchy process (AHP) approaches in Udham Singh Nagar of Uttarakhand. Sixty GPS-based surface soil samples were collected (0-30 cm depth) from different locations, and analyzed chemical properties using a stratified multistage random sampling method and maps were prepared to identify their spatial distribution. The results show that the values of soil fertility index on the fuzzy scale (0-1) was varied from 0.04-0.62 and, therefore, the study area was classified as very low, low, and moderate soil fertility classes comprising 55.61%, 44.24% and 0.14%, respectively. AHP analysis revealed that the most important limiting factor for wheat production was available nitrogen, followed by phosphorous, potassium, organic carbon, pH and electrical conductivity. A correlation coefficient between wheat yield and soil fertility index was found to be as high as 0.86, and its validating the zonation of soil fertility classes. This study infers that combined fuzzy-AHP techniques may be used to compute soil fertility index and limiting factors of wheat production.

Key words: *AHP, Chemical properties, Fuzzy, GIS, Zonation map*

Introduction

Food security is a major global distress due to the ever growing population. Many countries are facing severe scarcity of land for agricultural production throughout the world. High land use efficiency can

([1,2]Assistant Professor, [3]Scientist-C, [4]Scientist-C, [4]Ph.D Scholar, [5]Scientist, [6]Assistant Professor, [7]Assistant Professor, [8]Scientist)

increase yield per unit area and this is the most appropriate way to ensure food security rather than by extension of agricultural area. Arable land are limited in hilly area (Chapin *et al.*, 2011; Xingwu *et al.*, 2015), and in assessment to plain area of agricultural land at comparable latitudes, production is extremely poor. Soil fertility is a property that is in dynamic equilibrium which may alter according to natural and human-made conditions (Kavitha and Sujatha, 2015). There is a decline in soil fertility in many soils due to low nitrogen and phosphorus levels, which contribute to low productivity (Sanchez, 2002). Analyzing soil fertility is challenging since most soil chemical characteristics vary gradually and have considerable seasonal variation in both the situations, necessitating need for long term study. To augment quality crop management and to boost land productivity, decision makers must first identify the key factors that are restricting agricultural production (Rabia, 2012). Several studies have shown that soil qualities differ throughout agricultural lands, causing crop yields to fluctuate spatially. As a result, effective management is required to prevent harming the environment while satisfying the need for high agricultural production. Farmers should be instructed to employ a balanced application of manures/fertilizers, particular soil reclamation, and cropping pattern that are appropriate for their soil (Tagore *et al.*, 2014). A soil fertility evaluation utilizing a soil index might give critical information for plans and effective approaches to accomplish sustainable agriculture in the mountain area. Soil fertility maps can be created by using soil fertility index (SFI) readings and offer fertility management recommendations based-soil variability (Khaki *et al.*, 2017). When soil variability and its important evaluation indicators are recognized, improved needs and management recommendations restrictions that play critical roles in sustaining production may be alive defined for a given site (Xia, 2015). Soil fertility categorization, soil zonation mapping, and land appraisal have all made extensive use of fuzzy set theory (McBratney *et al.*, 2003; Lagacherie, 2005). Fuzzy model is one of the most adaptable methods for producing various types of soil map (Bagherzadeh *et al.*, 2018). For creating soil attribute maps, the model has good accuracy (Kremenova, 2005). Fuzzy logic converts imprecise information to precise knowledge and can create reasonable conclusions with faulty information. Because various soil quality indicators have varying effects on plant growth and development as well as on production, thus, it is important to appraise and evaluate all attribute based on its value, and the AHP is one helpful approach for calculating these weights (Keshavarzi *et al.*, 2020). Saaty's analytic hierarchy process (AHP) is a decision-making method that was developed in 1980 by Saaty AHP is a multi-criteria decision-making tool that enables decision-makers to prioritize and select alternatives based on a set of criteria (Chang *et al.*, 2007). Without requirement for particular facts, AHP relies on understanding and educated knowledge (Bottero *et al.*, 2011). However, fundamental disadvantage of AHP is that it treats expert opinion of people as a discrete digit between 1 and 9 and its Eigen values, which does not relation for the uncertainty coupled with this judgment. To solve this weakness, Fuzzy set was paired with the AHP approach to select the optimal option (Keshavarzi *et al.*, 2020). The combination of the fuzzy set with AHP results in accurate judgments and flexibility in decision making. In this current study, A soil fertility zonation map was prepared for identifying location-wise fertilizer application for wheat production based on soil reaction (pH), organic carbon (OC), electrical conductivity (EC), nitrogen (N), phosphorous (P), and potassium (K) with integrated Fuzz and AHP approaches.

Materials and Methods

Site description

The current investigation to assess soil fertility in Udham Singh Nagar district, Uttarakhand, India located in the Tarai region of the Kumaon Division (Figure 1). The total study area covers 3055 square kilometers and extends from (28°53' N-29°23' N) to (78°45' E-80°08' E). It is divided into seven districts: Bazpur, Gadarpur, Japsur, Kashipur, Khatima. Rudrapur and Sitargunj. The climate in the region was varies from subhumid to subtropical, with rainfall increases from south to north, although it may decrease from east to west. The annual rainfall averages roughly 1400 mm. approximately 90% of all rainfall is received during the monsoon season. Typic Ustipsamments, Udic Haplusstolls, Udifluventic, Ustochrepts, Udic Ustochrepts, and Typic Ustochrepts soil types are found in the district of Udham Singh Nagar.

Soil sampling and processing

In order to assess and investigate some chemical soil properties of surface soil samples were collected (0-30 cm depth) from sixty locations (Figure 2), and the coordinates of the sampling points were recorded using Garmin Oregon 550 GPS. A stratified multi-stage random sampling method has been adopted, and samples were collected during 2016-2017 from medium-status farmers. After soil samples have been collected from sixty locations, they need to be processed in order to prepare them for chemical properties analysis. The first step in the process is to air dry the samples in shade at room temperature, which is typically between 20-22 degrees Celsius. After processing, the soil samples are stored in appropriate containers and transported to a laboratory for analysis of chemical properties such as available nitrogen, phosphorus, and potassium, organic carbon, soil pH, and electrical conductivity in the soil physics and chemistry laboratory of GBPUA&T, Pantnagar, Uttrakhand. Based on the national bureau of soil survey and land use planning

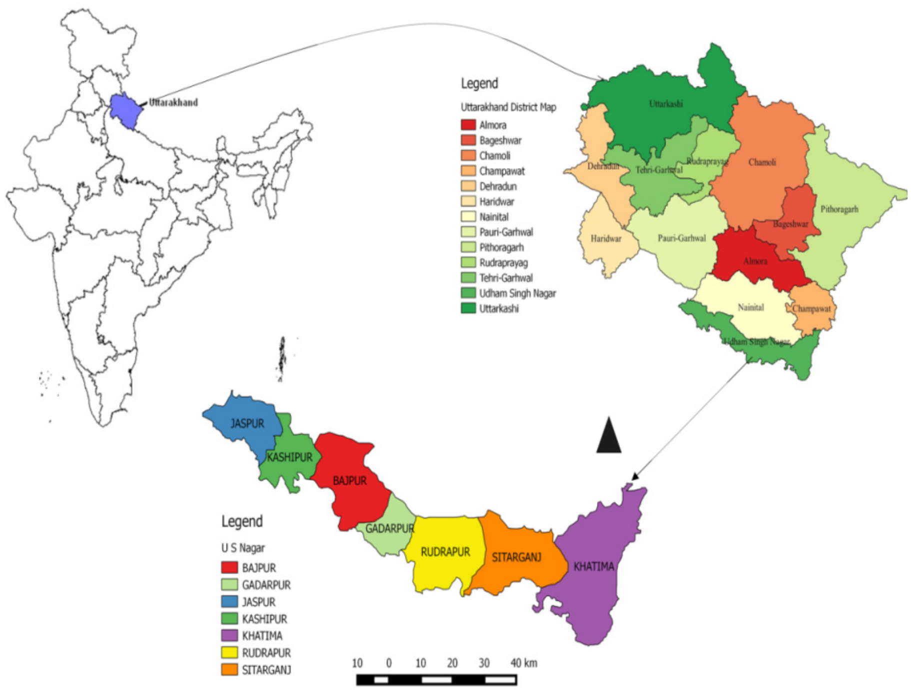

Fig. 1. Study area

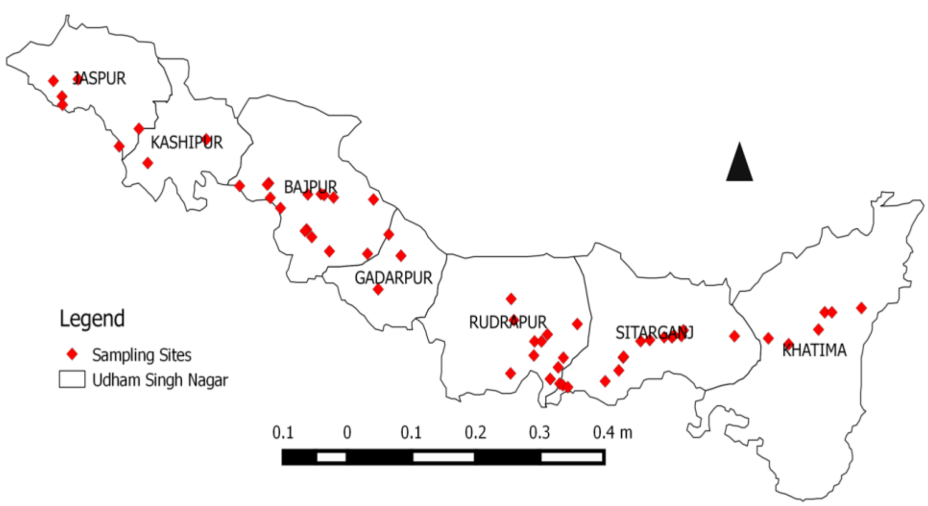

Fig. 2. Point location for soil sample collection of US Nagar

(NBSS&LUP) Nagpur, Maharashtra classification, the soils are shallow with sandy to loamy texture and composed mainly of gravel, sand, silt, and clay.

Wheat yield data

In order to validate the AHP-fuzzy soil fertility index, crop cutting experiment (CCE) data of wheat were collected from the Mahalanobis National Crop Forecast Center (MNCFC), New Delhi.

Fuzzy set theory

A fuzzy set theory describes uncertainty and imprecision in data and how they interact mathematically (Zadeh, 1965). In fuzzy set theory, fuzzification is the process of assigning numerical input to fuzzy sets with a certain degree of membership. Any number between 0 and 1 signifies the degree of doubt that belongs in the set. According to Burrough *et al.*, (1992), a fuzzy set (A) can be defined as follows:

For each $A = \{x, \mu A(x)\}\ x \in X$

Where, X=[x] represents a finite set point, and A(x) represents the membership function of x in A

Fuzzy membership functions can be bell-shaped, triangular, S-shaped, trapezoidal, sigmoid, and Gaussian. However, S-shaped fuzzy membership functions are linear for most soil factors (Oberthur *et al.*, 2000); thus, the S-shaped membership functions shown in equation 1 below is used in this study.

$$f(x,a,b) = \begin{cases} 0 & x \le a \\ 2\left(\frac{x-a}{b-a}\right)^2 & a \le x \le \frac{a+b}{2} \\ 1 - 2\left(\frac{x-b}{b-a}\right)^2 & \frac{a+b}{2} \le x \le b \\ 1 & x > b \end{cases} \quad .. (1)$$

Using the Linear Fuzzy transformation function, the user can specify a linear function between the low and high values. The value 0 will be assigned to any number lower than the minimum (certainly not a member), and 1 will be assigned to any number higher than the maximum (definitely a member). Lower and upper limits were assigned for available N, P and K, OC (%), pH and EC presented in Table 1. Further, The S-shaped membership values for all six soil parameters were computed based on equation 1 using MATLAB (Version R2019a).

Analytical hierarchy process (AHP)

Saaty (1990) has developed the AHP and it is one of the most important multi criteria decision making techniques. The process make use the technique of pair-wise comparison to decide the relation significance of each criterion, two at a time, to determine the weight values based on expert opinion (Miller *et al.*, 1998). The pair-wise comparison matrix is being used in the AHP, which determines the weights for each criterion by taking the Eigenvalue associated with the completed matrix's highest eigenvector and normalizing the factor sum to unity. Calculation of a pair-wise comparison matrix was done by using a scale from 1-9, where, 1 indicates the equal significance and 9 indicates extreme significance for the in-between criterion of the matrix shown in Table 2 (Malczewski, 1999, Feizizadeh *et al.* 2014).

Table 1. Critical values and soil fertility factors (mangle and adequacy limits) in the fuzzy membership function

Fertility factors	Lower limit	Upper limit
Available N. (kg/ha)	180	560
Available P. (kg/ha)	110	330
Available K. (kg/ha)	16	120
O.C. (%)	0.4	3.5
Soil reaction (pH)	5.5	10
E.C. (dS/m)	1	6

Where, N-Nitrogen, P- Phosphorous, K-Potassium, O.C.-Organic carbon, E.C.-Electrical conductivity

Table 2. The fundamentals scale for pair wise comparison matrix (Saaty, 2003)

Intensity of Importance	Definition
1.	Equal importance
2.	Equal to moderate importance
3.	Moderate importance
4.	Moderate to Strong Importance
5.	Equally Preferred
6.	Strong to Very Strong Importance
7.	Very Strong Importance
8.	Very to Extremely Strong Importance
9.	Extremely Importance

In the current investigation, pairwis e matrix computation was done by assigning weight values for six soil nutrient factors *viz.* available nitrogen, phosphorous, potassium, organic carbon, pH, and electrical conductivity presented in Table 3.

Furthermore, relative weights/eigenvectors were calculated for each factor using the method of Saaty (Saaty, 1990) as shown in Table 4. This method can

Table 3. The calculation of factor weight for pairwise comparison matrix

Parameters	Available N.	Available P.	Available K.	O.C.	pH	E.C.
Available N.	1	2	2	3	5	7
Available P.	½	1	2	3	5	8
Available K.	½	1/2	1	2	4	6
O.C.	1/3	1/2	1/2	1	3	5
pH	1/5	1/5	1/4	1/3	1	4
E.C.	1/7	1/8	1/6	1/5	1/4	1

Where, N-Nitrogen, P- Phosphorous, K-Potassium, O.C.-Organic carbon, E.C.-Electrical conductivity

identify and compute the inconsistencies of decision makers and this is a significant characteristic of this method (Feizizadeh *et al.,* 2014). The consistency ratio helps the determination of the constituency of the decision maker (Cengiz and Akbulak, 2009; Chen *et al.,* 2010), and is measured by equation (2).

$$Consistency\ ratio\ (CR) = \frac{Consistency\ Index\ (CI)}{Random\ Index\ (RI)} \quad ..\ (2)$$

The consistency ratio is calculated by using the consistency index (CI) and random index (RI). Consistency index (CI) when λ_{max} is the highest eigenvector of the computed matrix, which is measured by equation (3), and the 'n' denotes the order of the matrix. RI is the mean value of the CI depending on the computed matrix order specified by Saaty (1977) as depicted in Table 5.

$$Consistency\ index\ (CI) = \frac{\lambda_{max} - n}{n-1} \quad ..\ (3)$$

If the value of CR<0.10, the weight values of the matrix indicate consistency and the method (AHP) may provide meaningful results (Saaty, 1990).

Zonation map of soil fertility

The final soil fertility map is prepared by adding the fuzzification value of each parameter to the factor weight that AHP determined for that parameter. This process is shown in equation (4) (Kremenova, 2005):

$$SFI = w_i\mu_{A1} + \ldots + w_k\mu_{A1} \quad ..\ (4)$$

$$\mu_A = \sum_{j=1}^{k} w_j\, \mu_{Aj(x)} x \in X$$

$$\sum_{j=1}^{k} w_j = 1 \qquad w_j > 0$$

Where soil fertility index (SFI) is the AHP-Fuzzy soil fertility index, 'µ' is the membership values associated to each of the parameters and 'W' indicates the specific weight given to each of the parameters, 'i' and 'j' are nutrient parameter and weights respectively. QGIS software (Version 3.12) has been used to perform interpolation and fuzzy SFI mapping.

Table 4. The synthesized matrix for multi criteria decision making

Parameters	Available N.	Available P.	Available K.	O.C.	pH	E.C.	N.W.
Available N.	0.37	0.46	0.34	0.31	0.27	0.23	0.33
Available P.	0.19	0.23	0.34	0.31	0.27	0.26	0.27
Available K	0.19	0.12	0.17	0.21	0.22	0.19	0.18
O.C.	0.12	0.12	0.08	0.10	0.16	0.16	0.13
pH	0.07	0.05	0.04	0.03	0.05	0.13	0.06
E.C.	0.05	0.03	0.03	0.02	0.01	0.03	0.03

Where, N-Nitrogen, P- Phosphorous, K-Potassium, O.C.-Organic carbon, E.C.-Electrical conductivity, N.W.-Normalized Weight

Table 5. Random in consistency indices (RI) for n = 10 (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

After calculation of the SFI, thematic soil nutrients maps were prepared using inverse distance weighted (IDW) interpolation algorithm embedded in QGIS. The soil fertility index was further classified into five classes, which are presented in Table 6. A parametric test was carried out using point wheat yield data to authenticate the zonation of fertility class in the study area.

Table 6. The soil fertility values and classes (Nariyanti *et al.,* 2022)

Class	Fertility value	Fertility class
1	0.00-0.25	Very low
2	0.25-0.50	Low
3	0.50-0.75	Moderate
4	0.75-0.90	High
5	0.90-1.00	Very High

Results and Discussion

Exploratory analysis of data

In Table 7, descriptive information for chemical properties of soil is presented. The available nitrogen, phosphorous, and potassium values ranged from 136.10-364.16 kg/ha, 10.16-24.10 kg/ha, and 133.4-306.2 kg/ha, respectively. The pH of the soils was acidic to slightly alkaline ranging from 5.94-8.88. The soil electrical conductivity ranged from 0.06-2.61 dS/m, which indicates favorable conditions for production of wheat. Organic carbon levels range from 0.60-1.62% and are medium to high. High soil organic matter content of the soil enhance the water retention capacity and nutrient content and resulted in creating a favorable physical, chemical and biological properties environment (Khaki *et al.,* 2017; Fayyaz *et al.*, 2021).

Spatial distribution of soil nutrient parameters

Soil nutrient parameter available nitrogen, phosphorous, potassium and chemical properties including organic carbon, soil salinity and pH were estimated and their spatial distribution in the top 30 cm of the soil was interpolated using an inverse distant weighed method and mapped (Figure 3). The mean value of available nitrogen in the study area was 202 kg/ha which falls under low category based on classification of Subbiah and Asija (1956). Subbiah and Asija (1956) indicated that available nitrogen below 280 kg/ha is considered low; between 280 to 560 kg/ha is medium and greater than 540 kg/ha is high. Nitrogen is an essential nutrient plays an important role in the plant growth and development (Saber and Khalid, 2011). Unfortunately, the soils of the area under study have been found to have low nitrogen content, indicating that they are nitrogen-deficient and thus unable to support proper crop growth and development. This could be a cause for concern as it could lead to decreased yields and reduced profits from farming in the future. The mean value of available phosphorus content of surface soils of the study area is 14.0 kg/ha. Muhr *et al.*, (1965) indicated that available phosphorous below 22.9 kg/ha is considered low, between 22.9 and 56.45 kg/ha is medium, and greater than 56.45 kg/ha is high. Thus, the available phosphorous content of the composite surface soil samples of the experimental sites could be rated as low soil available phosphorous. Phosphorous plays a crucial role in cellular division and the formation of energetic structures (Bagherzadeh *et al.,* 2018). The mean value of available potassium is 175 kg/ha which can be classified as a low category as per the classification of Muhr *et al.,* (1965). Available potassium below 130 kg/ha is considered low, between 130-337 kg/ha is classified as medium and greater than 337 kg/ha as high. Potassium helps in the sugar translocation, opening closing of stomata, co-factor of many enzyme systems and reduces susceptibility to plant diseases (Bagherzadeh *et al.*, 2018). The pH is one of

Table 7. Statistics of soil properties in the study area (sample size = 60)

Soil parameters	Min.	Max.	Mean	S.D.	C.V. (%)
Available N. (kg/ha)	136	364	202	43	22
Available P. (kg/ha)	10	24	14	3	23
Available K. (kg/ha)	133	306	175	31	18
O.C. (%)	0.60	2	0.90	0.19	21
pH	6	9	8	0.68	9.0
E.C. (dS/m)	0.06	3	0.32	0.35	110

Where, Min-Minimum, Max-Maximum, SD-Standard Deviation, Coefficient of variation the most important soil chemical properties which influence development and plant growth by affecting ion exchange capacity and nutrient availability of soils. The mean pH values of soil samples of the study area were 7.57 and the soils are near neutral. Therefore, it can be inferred that pH of the soil is suitable for the cultivation of most crops. The organic carbon content of the soils of the area under

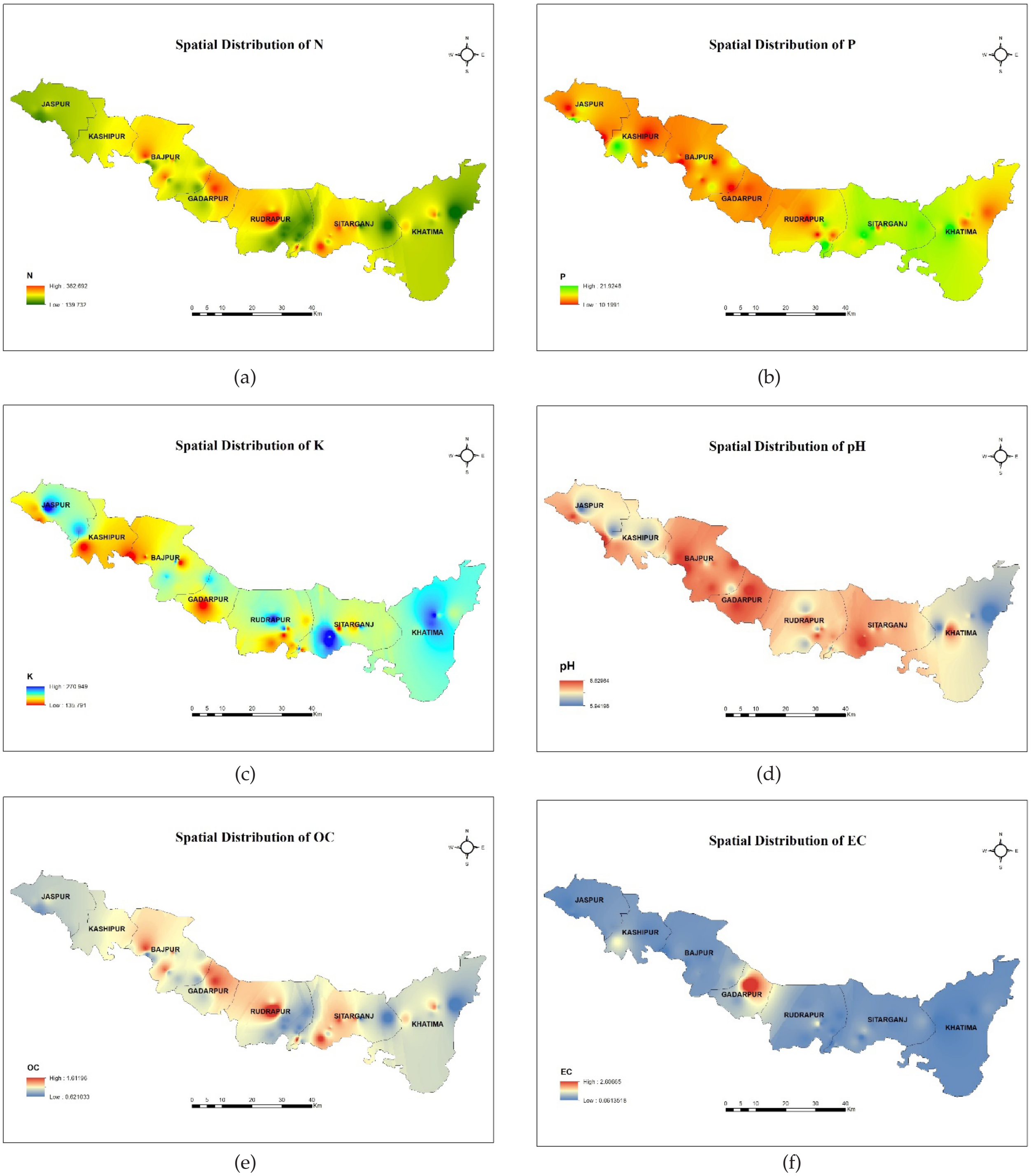

Fig. 3. Spatial distribution of available nitrogen (a), available phosphorous (b), available potassium (c), pH (d), Organic carbon (e) and EC (f) in the study area

study area was classified as medium to high organic matter content, which means the value constituted 0.90 %. The mean value of EC was 0.32 dS/m. It reveals that the soil is non-saline and plants can tolerate this amount of salts (Dahnke and Olson, 1990).

Consistency test of AHP

Maximum eigenvalue ($ë_{max}$) was computed for the consistency test of AHP, which is 6.34, using this value consistency index was calculated and found 0.068. Furthermore, the Random index (RI) is 1.24 for n=6 soil factors. The consistency ratio is computed as 0.055 using equation 2. The CR value of 0.055 in this study was within acceptable limits, and the weight values were found to be valid. All components of the vector sum had a combined total of one. Thus, a vector of weights is obtained reflecting the relative importance of the various factors from the matrix of paired comparisons. It was shown that the most important limiting factor was nitrogen with a weight of 0.33 and followed by phosphorous, potassium, organic carbon, pH and electrical conductivity with the weight of 0.27, 0.18, 0.13, 0.06 and 0.03, respectively. The least important factor was electrical conductivity, which clearly indicates the least limiting factor for wheat production.

Fuzzy soil fertility index and zonation map

The soil fertility factors were fuzzified using an S-shaped membership function. To determine the degree of membership for each factor, the lower and upper values of "a" and "b" were defined. Additionally, the factor weight obtained by AHP for the specific parameter, and the sum of the resulting values, were used to create the final soil fertility map presented in Figure 4. The soil fertility index values

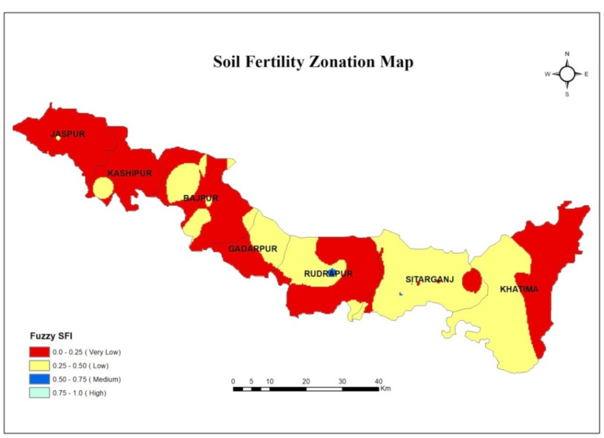

Fig. 4. The zonation of soil fertility values

ranged from 0.04 to 0.62 on a scale of 0 to 1, describing the study area as very low (1539 km², 55.61%), low (1224 km², 44.24%), and moderate (3.96 km², 0.14%) fertility classes. Jaspur and Kashipur blocks fall under the "very low fertility" class, while Sitargang block falls under the "low fertility" class. Four blocks Bajpur, Gadarpur, Rudrapur and Khatima vary from "very low" to "low fertility".

Validation of fuzzy soil fertility index

The soil fertility map was validated using observed crop-cutting experiment data from the study area. The Pearson correlation coefficient between soil fertility index and yield was as high as 0.86, as shown in Figure 5. This clearly demonstrates a good agreement between yield and soil fertility index.

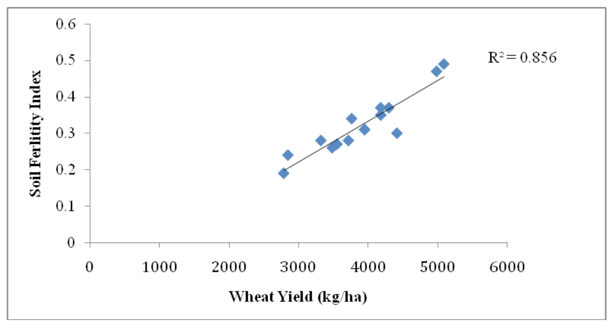

Fig. 5. Relationship between wheat yield and Soil fertility index

Conclusion

Combined Fuzzy and AHP techniques were used to compute the soil fertility index. The soil fertility index value in the degree of 0 to 1 ranged from 0.04 to 0.62, which designate the study area into very low (1539 km²), low (1224 km²) and moderate fertility (3.96 km²) classes comprising 55.61%, 44.24% and 0.14% of the study area, respectively. Results show that AHP plays a crucial role to identify the rank of limiting factors for wheat production. It was revealed that the most important factor influencing the soil fertility parameters was nitrogen with a weight of 0.33 and the least important factor was the electrical conductivity with a weight of 0.03. The correlation coefficient between wheat yield and soil fertility values was found 0.86 and it validates the fertility classes of zonation. The spatial distribution of classes shows that most of the blocks fallen in very low to low fertility zone, while very small areas were demonstrated as medium fertility zones. The poor values of soil fertility were contributed mainly to low amounts of nitrogen and phosphorous. Finally, it may be concluded that the integrated Fuzzy and AHP method has a good accuracy for producing soil fertility maps and thus, it is suggested that the fuzzy-AHP method would be used in soil fertility modeling in soil decision management.

References

Bagherzadeh, A., Gholizadeh, A. and Keshavarzi, A. 2018. Assessment of soil fertility index for potato production using integrated Fuzzy and AHP approaches, Northeast of Iran. *Eurasian Journal Soil Science*. 7(3): 203-212.

Bottero, M., Comino, E. and Riggio, V. 2011. Application of the analytic hierarchy process and the analytic network process for the assessment of different wastewater treatment systems. *Environmental Modelling and Software*. 26 : 1211-1224.

Burrough, P.A., MacMillan R.A. and Van, D.W. 1992. Fuzzy classification methods for determining land suitability from soil profile observations and topography. *European Journal of Soil Science*. 43(2): 193-210.

Cassel, G.M.A., Ludeke, M.K.B., Petschel, H.G., Reusswig, F., Plochl, M., Lammel, G. and Schellnhuber, H. 1997. Fuzzy logic based global assessment of the marginality of agricultural land use. *Climate Research.* 8(2) : 135-150.

Cengiz, T. and Akbulak, C. 2009. Application of analytical hierarchy process and geographic information systems in land-use suitability evaluation: a case study of Dumrek village. *International Journal Sustainable Development World Ecology*. 16(4): 286-294.

Chan, F.T.S., Chan, M.H. and Tang, N.K.H. 2000. Evaluation methodologies for technology selection. *Journal Materials Processing Technology.* 107: 330-337.

Chang, N.B., Parvathinathan, G. and Jeff, B.B. 2007. Combining GIS with fuzzy multicriteria decision-making for landfill sitting in a fast-growing urban Region. *Journal of Environmental Management.* 87(1): 139-153.

Chapin, F.S., Matson, P.A. and Vitousek, P.M. 2011. *Principles of Terrestrial Ecosystem Ecology*, Second ed. Springer, New York.

Chen, H., Liu, G., Yang, Y. and Ye, X. 2010. Comprehensive evaluation of tobacco ecological suitability of Henan Province-based on GIS. *Agricultural Science China.* 9(4): 583-592.

Dahnke, W.C. and Olsen, R.A. 1990. Soil test correlation, calibration, and recommendation. In: R.L. Westerman (ed.) *Soil Testing and Plant Analysis*, 3rd ed., SSSA Book Series: 3, Soil science society of America. Madison, WI, 45-71.

Fayyaz, H., Yaghmaeian, N., Sabouri, A. and Shirinfekr, A. 2021. Assessing soil fertility index using Fuzzy-AHP and parametric methods for tea cultivation with different productivities. *Journal of Agricultural Engineering Soil Science and Agricultural Mechanization, Scientific Journal of Agriculture.* 44(3) : 275-294.

Feizizadeh, B., Jankowski, P. and Blaschke, T. 2014. A GIS-based spatially explicit sensitivity and uncertainty analysis approach for multi-criteria decision analysis. *Computer Geo Science.* 64: 81-95.

Kavitha, C. and Sujatha, M.P. 2015. Evaluation of soil fertility status in various agroecosystems of Thrissur District, Kerala, India. *International Journal Agricultural Crop Science.* 8: 328-338.

Keshavarzi, A., Tuffour, H.O., Bagherzadeh, A., Tattrah, L.P., Kumar, V., Gholizadeh, A. and Rodrigo-Comino, J. 2020. Using fuzzy-AHP and parametric technique to assess soil fertility status in Northeast of Iran. *Journal of Mountain Science.* 17(4): 931-948.

Khaki, B.D., Honarjoo, N., Davatgar, N., Jalalian, A. and Golsefidi, H.T. 2017. Assessment of Two Soil Fertility Indexes to Evaluate Paddy Fields for Rice Cultivation. *Sustainability.* 9: 1299.

Kremenova, O. 2005. *Fuzzy modeling of soil maps*. M. Sc Thesis, Helsinki University of Technology, Department of Surveying, Finland, 81.

Lagacherie, P. 2005. An algorithm for fuzzy pattern matching to allocate soil individuals to pre-existing soil classes. *Geoderma.* 128 : 274-288.

Levary, R.R. and Wan, K. 1998. A simulation approach for handling uncertainty in the analytic hierarchy process. *European Journal Operational Research.* 106(1): 116-122.

Malczewski, J. 1999. *GIS and Multi-Criteria Decision Analysis*, Wiley, London.

McBratney, A.B., Mendonca, S.M.L. and Minasny, B. 2003. On digital soil mapping. *Geoderma.* 117: 3-52.

Miller, W., Collins, W., Steiner, F.R. and Cook, E. 1998. An approach for greenway suitability analysis landscape and urban planning. *International Journal Geographic Information Science.* 42(2-4): 91-105.

Muhr, G.R., Dutta, N.P., Subramanoey, S. 1965. *Soil Testing in India* USAID, New Delhi, India.

Nariyanti, S., Herawati, A., Herdiansyah, G., Irianto, H., Riptanti, E. W. and Qonita, A. 2022. Soil fertility index based on altitude: A comprehensive assessment for the cassava development area in Indonesia. *Annals of Agricultural Sciences.* 67(2): 158-165.

Oberthur, T., Dobermann, A. and Aylward, M. 2000. Using auxiliary information to adjust fuzzy membership functions for improved mapping of soil qualities. *International Journal of Geographical Information Science.* 14(5): 431-454.

Rabia, A.H. 2012. A GIS-based land suitability assessment for agricultural planning in KilteAwulaelo district, Ethiopia. In: *Proceedings of the 4th International Congress of ECSSS, Eurosoil "Soil Science for the Benefit of Mankind and Environment", Bari, Italy.*

Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*. 15: 234-281.

Saaty, T.L. 1990. The analitic hierarchy process in conflict management. *International Journal Conflict Management.* 1(1): 47-68.

Saaty, T.L. 2003. Decision-making with the AHP: Why is the principal eigenvector necessary. *European Journal of Operational Research.* 145(1): 85-91.

Saber, F.H. and Khalid, A.K. 2011. Effect of chemical and organic fertilizers on yield and essential oil of Chamomile Flower Heads. *Medicinal and Aromatic Plant Science and Biotechnology.* 5(1): 43-48.

Sanchez, P.A. 2002. Soil fertility and hunger in Africa Science, *295*(5562), 2019-2020.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Currence Science.* 25: 259-260.

Tagore, G. S., Singh, B., Kulhare, P.S. and Jatav, R.D. 2014. Spatial variability of available nutrients in soils of Nainpur tehsil of Mandla district of Madhya Pradesh, India using Geo-statistical approach. *African Journal of Agricultural Research.* 10(34) : 3358-3373.

Xia, M., Zhao, B.Z., Hao, X.Y. and Zhang, J.B. 2015. Soil quality in relation to agricultural production in the North China Plain. *Pedosphere.* 25: 592-604.

Xingwu, D., Li, R., Guangli, Z., Jinming, H. and Haiyan, F. 2015. Soil productivity in the Yunnan province: Spatial distribution and sustainable utilization. *Soil and Tillage Research.* 147 : 10-19.

Zadeh, L.H. 1965. Fuzzy sets. *Infor Control.* 8: 338-353.