Rule Descriptions for Soil Quality and Soil Fertility Assessment using Fuzzy Control System

Himanshu Pant, Manoj Chandra Lohani, Ashutosh Bhatt, Janmejay Pant, Manoj Kumar Singh

Abstract: The three major elements or fertilizers of the soil are Nitrogen (N), Phosphorus (P) and Potassium (K). These three elements are necessary for the plants development and increase the productiveness of the soil. The trend for categorizing soil quality for the diversity of usages is by calculating the Soil Fertility Indexes (SFI). In this paper, we have created a fuzzy control system using scikit-learn-fuzzy or skfuzzy (Fuzzy Logic Toolbox for Python) for Soil quality and fertility assessment, based on fuzzy rules to suggest suitable nutrients for the crops and relate to linguistic classification of soil excellence with degree of confidence in Nainital district of Uttarakhand, India.

Keywords: Fuzzy control system, Fuzzy logic, Fuzzy rule-based system, Linguistic term, Soil fertility, Soil quality

I. INTRODUCTION

Soil is a significant component of farming. There are numerous categories of soil in India. Each category of soil can have diverse kinds of structures and different kinds of yields produce on diverse forms of soil. Environmental and biological preservation will only be accomplished by conservation and augmentation of soil quality. Soil nutrients are the essential factors that provide soil productiveness and supplementary environmental aspects [1]. Farming is the mainstay of India's economy. It makes available the employment up to 80% of the Indian inhabitants [2]. It shares 26% of the gross domestic product. It make certain food security for the nation and provides numerous raw ingredients for productions [3].

A soil quality is a complex characteristic of land which has well understood impact over the capability of field for a specific usage. To understand soil quality we have to study individual soil characteristics. Individual soil qualities are the obtainability of soil moisture to grow the plants, erosion resistance and the capacity of the soil to hold nutrients percentage or how much nutrients present into soil. Soil quality may be measured or calculated because soil quality cannot measure directly.

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One word is common with respect to soil qualities is soil health. We can interchange the terms Soil health and soil quality synonymously. Soil quality has much weightage on soil biodiversity. Soil quality is the ability within natural or managed ecosystem boundaries to perform a specific kind of functions. The constitutive objective of soil quality research is to acquire how to manage different types of soil in such a way to improves soil function.

Farming growth is, therefore, a precondition of national fortune. Indian agronomy is composed of numerous harvests, with the leading food affixes being rice and wheat. Farmers also cultivate a variety of pulses, different types of potatoes, sugarcane, various oilseeds, and different non-food items like coffee, cotton, tea leaf, rubber etc.

Soil quality assessment is the process to measure the changes in soil as we endeavour to obtain soil to perform what we would like to do. The information essential to shield and improve long term agricultural production, water quality and habitats of all organisms including people is done by assessing soil quality. Soil is one of the natural resources and provides plants all its nutrients required during photosynthesis. It is the physical world of various breathing organisms and is crucial things in agriculture [4].

We cannot measure soil quality directly. To measure soil quality, we assess indicators. An indicator of soil is a quantifiable property that indicates how well the soil can function. It can be substantial, chemical, and organic properties, methods, or features of soils.

The soil construction is affected by external factors such as temperature, wind, rainfall, humidity, sunlight. These factors are crucial in bringing about modifications in the texture and feature of the soil. The type of crop that would be grown using a particular type of soil is determined by the components of soil and the climatic influence of a region.

Soil quality is a complex property. It is not a single attribute or single characteristic is required to study. It is a property of physical function, chemical functions and biological functions of soil factors because we understand soil is dynamic body. These factors affect the environment quality. So soil quality is related to our environment. It affect directly or indirectly to air quality, water quality and soil quality. In water quality, it purifies water for us. Air quality when suspended elements remain rest in the air. It is directly related with soil. This soil quality is related with our agricultural sustainability. If we want to assess the particular system is sustainable or not sustainable, we assess quality of soil [5]. Soil quality is defined as how well soil and nutrients performs what we want it to do on soil. Particularly, soil quality and soil health is the ability to perform a specific function within natural or managed ecosystem boundaries on a precise variety of soil to maintain plant growth and animal productivity.

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Plants are the main source of NPK which affects the physical and chemical properties of soil [6]. Soil quality also maintains and enhances the quality of water and air, and also support human health and surroundings [7].

Soil fertility is the capability of soil to endorse agricultural plant growth, i.e. soil fertility provides plant environment and sustainable results to produced consistent yields of high quality. The fertility of the soil is considered by numerous parameters such as sun light, composition of soil attributes, pH value, nutrients and atmosphere change [8]. Soil quality has been considered by utilization of soil quality indicators. At present, the estimation of soil quality by using indicators is hot topic in the scientific research literature view [9]. The objective of this study is dealing with vagueness and partiality exist in the soil fertility domain expert's perception in describing soil quality in linguistic terms such as Low, Medium, and High for the well-defined objective [10].

Rating of soil quality parameters in various linguistic terms contains vagueness and fuzziness. This vagueness is term as epistemic uncertainty. Uncertainty in soil quality parametric data due to randomness inherent variability is known as statistical or aleatory uncertainty. Fuzzy inference system and fuzzy rule based concepts are useful technique for modelling both aleatory and epistemic uncertainty [11].

This study is constructed on evolving a fuzzy inference system [12] to understand fuzzy rule based outcomes of pH, total nitrogen, phosphorus, and potassium acquired from soil tests carried on soil parameters taken from Nainital (a district of Uttarakhand, India). The results would also be suggested to apply specific amount of fertilizer components (NPK) to restore soil fertility to a finest level.

This study would also be suggested to use better crops and decline in crop loss from the incorrect use of fertilizer. The paper structured is as follows: Section-1 describes the introduction and literature review that cover the significance of the suggested scientific need-based research. Section-2 defines the theoretical foundation of fuzzy logic rule-based classification and terminologies used in fuzzy logic. System implementation and details of the experimental performance are presented in section 3. Section 4 comprises a conclusion.

II. THEORITOCAL FOUNDATIONS

A. Research Study Area

The research study site is Nainital [13], which is a district of Kumaoun division in Uttarakhand state (India). Nainital is a scenic spot situated in the lap of western Himalaya. Nainital is located at 29.395_N_79.449_E and elevated 2,084 m (6,837 ft) above sea level. Summer season (usually spanning from March-June), the monsoon season (from July-October) and winter season (from October-February) are the various climate in Nainital. The average temperature of the Nainital site is 13.50C. As of 2011 India census, the area is well populated having a population of 41,377 and having a density of 3500/km2 (9100/sq mi) with farming as a main source of earning. The different types of soils in different regions of western Himalaya belong to Inceptisols, Entisols, Mollisols, and Alfisols category [14].

B. Problem statement

Objective of this study is to compute the soil quality and nutrient fertility management relates to linguistic classification [15] using a fuzzy inference system (FIS). Opinion of the domain expert's for ranking linguistic soil quality parameters may contain vagueness. For describing uncertainty [16], fuzzy logic concepts [17] and fuzzy rule based approached plays a vital role with fuzzy inference system. However there was no scientifically method of quantifying these types of imprecision and uncertainty, before the theory of fuzzy sets.

Whenever we have to define haziness, ambiguity, vagueness, and ambivalence in conceptual or mathematical models of empirical phenomena, fuzzy sets are useful to assess the soil quality [18].In reality uncertainty, imprecision and ambiguity are inevitable or inherent parts of natural systems. The fuzzy set theory and fuzzy inference system are used to create fuzzy rules to deal with such uncertainty in soil quality assessment.

III. METHODOLOGY

The mathematics produced by conventional logic for fuzzy inference system is reliable, and the fuzzy set theory may be seen as a generalization of classical set theory. The fuzzy logic-based approach using fuzzy control system used in describing soil quality in the Nainital region is detailed in this section.

A. Fuzzy Set

A fuzzy set is the ordered pair of data elements and a membership grade value. The fuzzy reference set is called the universe of discourse, and for each element, the value in reference set is called the degree of membership. The fuzzy set element's membership degree lies between 1 and 0 including 1 and 0.Fuzzy sets are represented with a tilde sign (~) in a set. In a fuzzy set, partial membership exists when a member of one fuzzy set can also be a part of another fuzzy set in the same universe of discourse. The elements in the set that have varying degrees of membership are known as partial membership. We can understand the difference between classical set and fuzzy set using membership grade values [19]. In classical set, elements are satisfying the exact properties of membership. On the other hand fuzzy set hold the elements that satisfy the continuous properties of membership. A fuzzy set A in the universe of discourse U can be described as a collection of ordered pairs as-

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x) | x \in X$$

Where $\tilde{A}$ is the fuzzy set, x is the element or member of the set, $\mu_{\tilde{A}}(x)$ is the membership grade of the element x in a fuzzy set A.

B. Membership function and fuzzy numbers

A membership function on the universe of discourse U for a fuzzy set A is defined as $U(\mu A) \rightarrow [0,1]$, where each element in universe of discourse U is represent to a value between 0 and 1. This value is called membership value or degree of membership of the elements of a set in universe U to the fuzzy set A.

We can represent a fuzzy set graphically by using membership functions. Universe of discourse is represented in horizontal axis, whereas the degrees of membership in the [0,1] interval is represented in vertical axis.

C. Crisp set

Crisp set is also known as a conventional set. It is a group of diverse objects. Crisp sets are the collections of the elements in which an element is either a member of the set or not. The crisp set is defined in a way that the universe of discourse is divided into two parts members and non-members. The elements of the crisp set do not share their boundaries. That is there is no intersection between them. The crisp sets are also known as a disjoint set. The crisp sets are implemented with strict boundaries. That means the element comes in the particular set boundary belong to 100% to that set and those elements which are outside of the particular set boundary that elements belong to 0% to that set.

The general form of the crisp set is:

$$X_A(x) = \text{def} \begin{cases} 1 & if \ x \in A \\ 0 & if \ x \notin A \end{cases}$$

This syntax shows that any element belong to 100% to a set if the membership value is exactly 1 and an element x does not belong to set A if the membership value of an element is 0.

D. Fuzzy Logic

The term fuzzy logic was first coined by Dr. Lotfi Zadeh in the 1960s. Fuzzy means unclear, uncertain or vague in nature. In the classical system Boolean value 1 represents the true state of a system while Boolean value 0 represents the false state of a system. There is no concept of absolute true and absolute false situation in fuzzy logic. Fuzzy logic provides the concept of an intermediate value between 1 and 0. These intermediate values are known as partially true and partially false [20]. Fuzzy Logic deals with the fuzzy set or fuzzy algebra. Fuzzy logic is used to create a fuzzy control system for describing fuzzy rules, exploration of nebulousness in natural language processing and numerous application domains.

E. Linguistic Variable

In a fuzzy control system, each fuzzy set describe in some linguistic terms like very low, low, average, high, and very high. The linguistic terms are correspondence with the numerical values of soil properties. The pH level range is given in Table-1. In our data set, we have used Low, Medium, High and Excessive linguistic terms for the nitrogen, phosphorus and potassium fertilizers in Table-2.

Table I: Soil pH in Linguistic Term

S.No.	Soil pH	pH in Linguistic Term
1	<7	Acids
2	7	Neutral
3	>7	Alkaline

Table-II: NPK Fertilizer Level

Fertilizer	Fertility Level			
	Low	Medium	High	Excessive

Nitrogen	<10	20-Oct	20-30	>30
Phosphorus	<20	20-40	40-100	>100
Potassium	<150	150-250	250-800	>800

F. Fuzzy Rule-Based System

The fuzzy classification rules for soil quality indicate a certain value of classification. The greater possibility of soil quality is classified in a particular class using greater degree of match. A fuzzy rule-based system was constructed to define the soil quality and fertility levels as low, medium and high. These descriptions in linguistic terms for each parameter have consistently nebulous information on the soil health. A sample fuzzy rule with NPK fertilizers are processed using conjunction and disjunction operators in Table-3 for knowledge base. The acceptable quality of soil is calculated with maximum degree of assertion. Figure-3 represents the ordered arrangement for soil quality cataloguing [21] and Figure-1 represents the Fuzzy Inference System for soil Quality classification.

Table-III Fuzzy Rules for soil Quality

Rule No	Soil Quality Rule (Antecedent)	Linguistic Class(Consequents)
Rule-1	If Nitrogen is Excessive and Phosphorus is Excessive and Potassium is Excessive	Soil Fertility is Low
Rule-2	If Nitrogen is High and Phosphorus is Excessive and Potassium is High	Soil Fertility is High
Rule-3	If Nitrogen is Medium and Phosphorus is High and Potassium is Medium	Soil Fertility is High
Rule-4	If Nitrogen is Low and Phosphorus is Excessive and Potassium is High	Soil Fertility is Low
Other Rules……….		

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Membership Grade of Nitrogen

Membership Grade of Phosphorus

Membership Grade of Potassium

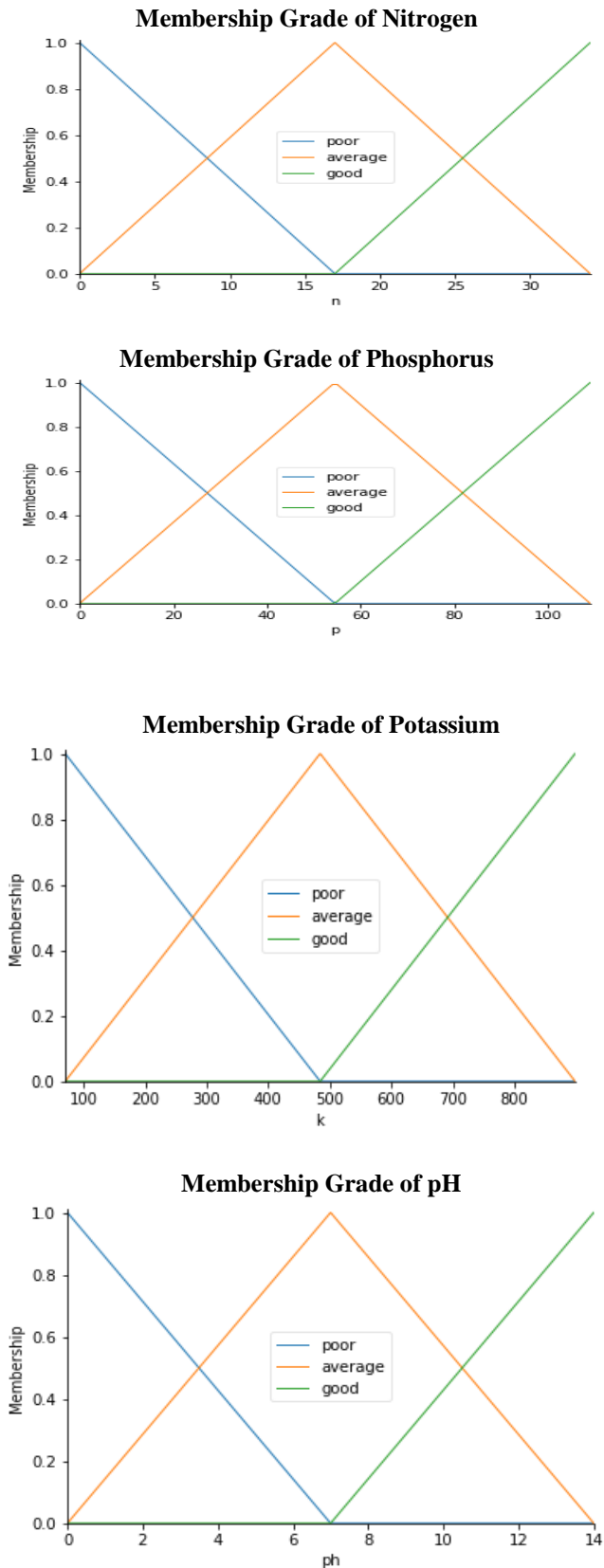

Membership Grade of pH

Fig. 1. Membership Grades of soil Nutrients

IV. DATA SET DESCRIPTION

A Soil testing was performed on a soil samples taken from diverse chunks of a field in the Nainital district (Uttarakhand).These soil samples were mixed after collecting it and then tested in the laboratory and from the quantitative result value of the soil fertilizers like levels of

nitrogen, phosphorus, and potassium in the soil samples. On the basis of soil fertility levels, we can classify the soil data which were taken from one of the soil testing laboratory in the Nainital. We have implemented fuzzy inference system for generating the fuzzy rules designed using python's skfuzzy tool. Through these fuzzy rules, we can further categorise our data set and then we can forecast on the test data. On the basis of different soil properties, we can define the soil quality and fertility in three different linguistic terms. These linguistic terms are Low, Medium and High.

For this purpose we have collected the 106 samples of soil from the three different regions of Nainital district (Uttarakhand) by random sampling technique and then sent to the soil testing laboratory for quantifying the properties of soil. The collected data set bipartite in independent and dependent attributes. Table-4 describes the soil attributes collected from each soil sample.

Table-IV: Soil Attributes Description

Soil Attributes	Description
pH	pH value of soil for nutrients
EC	Soil electrical conductivity
OC	Organic carbon
N	Total Nitrogen
P	Total Phosphorus
K	Total Potassium
S	Total Sulphur
ZN	Zinc
B	Boron
Fe	Total Iron in soil
Mn	Manganese
Cu	Uniformity coefficient
Soil Fertility Level	Dependent Variable for soil quality

V. EXPERIMENTS AND RESULTS

The soil quality can be described in various linguistic terms. Initially we modelled the vagueness in the perspective of expert's perception and then define the fuzzy set for a degree of certainty of soil quality as Low, Medium and High. We have applied fuzzy logic in the SKFUZZY package of python to simulate the control system for soil quality analyses; we had created a Control System Simulation using a skfuzzy package in python. Using python API in the antecedent labels of fuzzy control system; we had pass and simulated the system by specifying the inputs and calling functions. Once the quality is figured, we can interpret the result and visualize these results in figure-3. This figure shows that we get a real-world answer in the form of crisp value from the fuzzy membership input functions i.e. soil quality. For this purpose, the centroid method of defuzzification is used.

The domain experts' rules and perceptions can be analysing using the power of fuzzy logic. As specified above descriptions; we have processed 106 soil samples from the different locations of the Himalayan band in Nainital.

After the collection of the soil data, it is bipartite into antecedent and consequent objects which contain the pair of variables values and membership functions. The relationship between elements and membership functions of the antecedent and consequent can be view by using view () in the skfuzzy tool in python as shown in the figure. We have defined the fuzzy relations between crisp input to crisp output to make these output by some fuzzy rules. Mapping the imprecise rules (we take only 4 rules) into a defined soil quality as shown in figure-2.
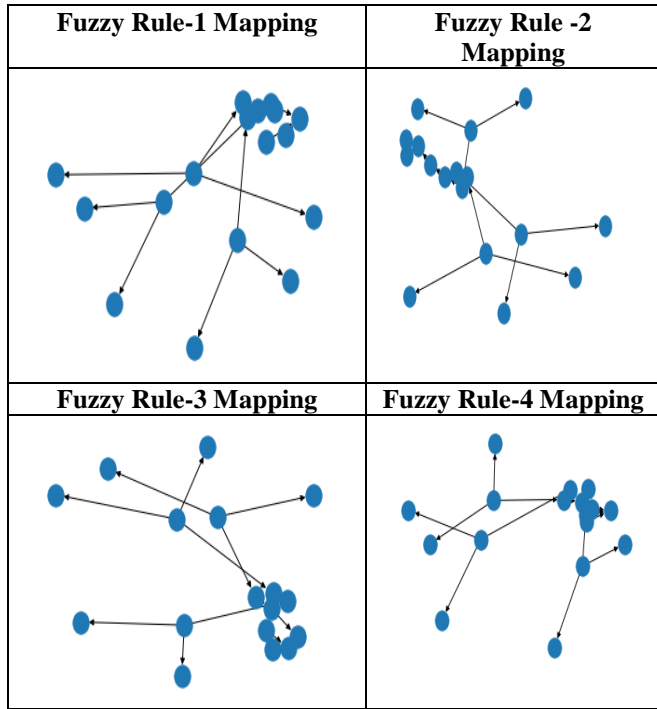

Fuzzy Rule-1 Mapping	Fuzzy Rule -2 Mapping
Fuzzy Rule-3 Mapping	Fuzzy Rule-4 Mapping

Fig.2. Fuzzy Rules Mapping

After obtain the activity of each output membership functions using conjunction and disjunction operator; they all must be combined. This is typically done using a maximum operator. This step is also known as aggregation or Mapping of rules as shown in the figure-3.
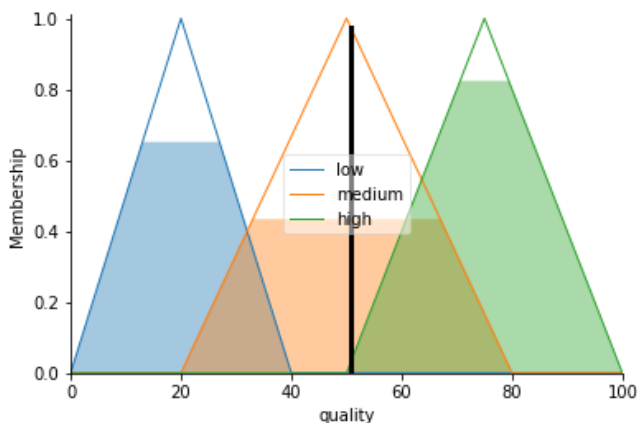

Fig.3. Suggested Soil Quality

The aggregated membership and soil quality of the Nainital district (Uttarakhand, India) after simulating is 50.84%. That means the soil quality of the Nainital district in the linguistic term is medium and with the help of soil nutrients and mapping with each parameters of soil, we can improve the soil fertility and soil quality.

VI. CONCLUSION

A fuzzy rule-based is proposed in the direction of soil quality assessment with soil fertility level classes using fuzzy logic in different linguistic terms with a degree of uncertainty. The dependent variable or class named fertility level is considered in three different levels in linguistic-based on the soil attributes. The fuzzy logic theory is applied for creating different rules on the independent variables like NPK (Nitrogen, Phosphorus and Potassium) for fuzzification and finally defuzzified the output using the centroid method of defuzzification for the crisp value.

VII. FUTURE SCOPE

In current research, fuzzy rules and fuzzy sets of the fuzzy logic domain are extensively used in agricultural science. Further we will do this consignment of soil quality assessment and improvement the nutrients ratio in the soil using artificial neural networks, conventional neural network, neuro-fuzzy hybrid technique, machine learning techniques etc. Deep learning is one more significant aspect through which we can implements a classification and regression model to predict soil quality and soil fertility.

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