HYDROLOGICAL SOIL CLASSIFICATION – A FUZZY APPROACH

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ABSTRACT

Hydrological response of an area is influenced by the soil characteristics of that area. Hydrological Soil Classification (HSC) refers to a group of soil series that can be considered homogeneous in respect of soil characteristics that influence the run-off. The HSC is required for a spectrum of hydrological applications by agriculturists, engineers and soil conservationists. The main soil parameters considered for the HSC are effective depth, soil texture, clay percentage, and infiltration. It has been observed that generally uncertainty prevails in various classification approaches.

In the present study hydrological soil classification has been carried out using Fuzzy Logic. Fuzzy Classification deals with approximate modes of reasoning. Its chain of reasoning is short and everything in it is a matter of degree. This degree is represented by membership function. This function can be generalized such that the values assigned to the elements of a set fall within a range of 0 to 1.
During this work, it has been observed that while using Soil Conservation Services (SCS) approach for HSC, it is difficult to draw definite conclusions. While Maximum Likelihood Classifier (MLC) yields a definite group but it assumes soil boundaries to be crisp. This assumption is generally not valid in nature. To remove the uncertainty present in the classification, Fuzzy Maximum Likelihood Classifier (FMLC) approach was used. For this membership functions for various properties of the soil were generated in the MATLAB environment and these were incorporated for soil classification..

Keywords—: Hydrological Soil Classification, Maximum Likelihood Classifier, Fuzzy Maximum Likelihood Classifier, Remote Sensing, MATLAB.

INTRODUCTION

Soil is the largest natural resource for the use of human beings, plants, animals etc. Soils are one of the most valuable natural resources of a nation. Quality of soils and kind and quality of plants and animals grown and fed on them often determine man's standard of living [27]. Hydrological properties of soil have been of interest both to hydrologists and soil scientists for a long time.

Understanding of soil and their classification is important to all those involved with developmental activities for example agriculturists, geologists and engineers [36]. From various classification techniques like Particle Size Classification, AASHTO Classification System etc., this paper deals with Hydrological Soil Classification (HSC), which indicates run-off potential of a particular soil or groups of soils. The main parameters for this classification are effective depth, infiltration, permeability and soil stratum etc. By considering all these parameters, the soils are classified hydrologically in four groups Group A,B,C,D as per Musgrave Classification System. HSC is useful for the estimation of Run-Off. It is required for the study of overland flow characteristics and to find out the run-off generated from an area. This classification is also essential to predict the behaviour of soil under irrigation, its suitability for irrigated cultivation, silting of canals and other irrigation works, to determine the drainage needs of specific soil types, to find the erosion control need, and to aid in determining the optimal cropping pattern for a particular soil.

Fuzzy logic, which is a superset of conventional (Boolean) logic, can provide a better representation for geographical phenomenon, many of which can't be described properly by a single attribute (9). In a fuzzy representation, land cover classes can be defined as fuzzy sets and pixels as set elements. Each pixel has attached to it a group of membership grades to indicate the extent to which the pixel belongs to certain classes. Pixels with class mixtures or in intermediate conditions can now be described (40).

The objective of this paper is to develop an approach for HSC using Fuzzy logic. To achieve this objective, initially relation between Fuzzy Logic and HSC is determined and then by using MATLAB, Fuzzy membership functions were calculated which were used for determining the HSC in the studied area..

LITERATURE REVIEW

A Hydrological Soil Classification (HSC) refers to a group of soil series that can be considered homogeneous in respect of soil characteristics that influences the run-off. This classification considers soil particle size, shape, permeability, infiltration values and effective depth for grouping the soil into various classes [29]. Main approach for classifying soil hydrologically is Soil Conservation Services (SCS) approach. The SCS method is most popular for HSC as it is a reliable procedure, computationally efficient, less inputs are required, and it also relates Run-Off to Soil Type, Land use and Management Practices. Parameters Affecting Hydrological Behavior of a Soil are Effective Soil Depth, Soil Texture, Clay Content, Soil Structure, Infiltration and Soil Permeability. Soil Conservation Services (SCS) of the US Department of Agriculture has classified the soils into four hydrological soil groups namely Group A, Group B, Group C and Group D respectively in the increasing order of run-off potential. Fuzzy Logic is a superset of conventional (Boolean) Logic that has been extended to handle the concept of partial truth – truth values between "Completely true" and "Completely false". Fuzzy logic is a convenient way to map an input space to output space [26]. This is the starting point for everything else, and the great emphasis here is on the word convenient. As the Lotfi Zadeh, who is considered as Father of fuzzy logic once remarked "in almost every case one build the same product without fuzzy logic, but fuzzy is faster and cheaper [43]." Fuzzy logic deals with approximate modes of reasoning. Its chain of reasoning is short and everything in it is a matter of degree. Its distinguished characteristics are that premises and conclusion is a canonical form [13]. Classification is the process of categorizing the pixels of an image into different groups/classes such that pixel in one class has similar characteristics. Thus, it helps in better understanding of the imagery. Fuzzy Classification is a kind of sub-pixel classification [40]. When a pixel consists of more than one class, the ambiguity arises as to which class the pixel has to be assigned.

Fuzzy set theory resolves this ambiguity by assigning membership functions, which indicates the class proportions within the pixel. There are various conventional techniques like Maximum likelihood classifier, Parallelepiped classifier etc., but there are many drawbacks associated with these conventional techniques. Fuzzy Maximum Likelihood Classifier is the most widely used classifier for the classification of remote sensing data. It has generally been used as a crisp classifier [40]. It allocates a pixel to the class based on the probability of a pixel belonging to that class. In its crisp form, a pixel is allotted to the class having the highest probability. On the other hand, the probability values obtained from Maximum Likelihood Classifier (MLC) indicates the proportion of various classes inside a pixel. Thus, these probabilities may be considered as fuzzy outputs and classifiers may be called as a FMLC. Typically, MLC involves three stages: Training, Allocation and Testing which are discussed in following paragraphs:

A) Training: In case of crisp classification, the training data statistics include the conventional mean and variance and covariance matrix [41]. The training samples selected to compute these statistics should be sufficiently homogeneous (i.e the pixels should be pure). These statistics are given as follows:

Mean = µ1(x) = and Variance – Covariance Matrix =

To get the fuzzy classified output from MLC, the requirement for pixels to be homogeneous is less important [41] and therefore a training sample may contain mixed pixels. The fuzzy mean and fuzzy variance – covariance matrix can be computed as follows :

Fuzzy Mean, µ¬¬i*(x) = and Fuzzy-Covariance, where fi(xj) is the membership values of class I in a pixel and xj is the pixel value vector (1<j < n) in ‘k’ bands.

B) Allocation: In crisp classification, the pixel is assigned to the class whose probability is the highest among all other classes. The probability of a pixel belonging to class i is given as = [In fuzzy classification, the membership value of a pixel to class i, can be computed from fi(x)= where Pi(x) is given by equation (v) except that µi and ∑i respectively are replaced by µi* and ∑i* . The membership values indicate the class proportions of a pixel.

STUDY AREA AND DATA

The present study has been carried out in an area close to Roorkee. It is bounded between longitude $77^0$30’E to $78^0$15’E and latitude from $29^0$45’N to $30^0$00’N. Roorkee, Bahadrabad, Roshnabad and Aurangabad are the important places in the study. Solani, Ratmau, Pathri and Ranipur Rao drain are the main drains in this area.

In general, coarse grained soil and land devoid of agriculture is closer to foothills and fine grained soil and irrigated land is closer to water bodies, river courses. The intensity of agriculture is increasing from

North to South and soil grain size also has been found to be decreased from North to South. Annual rainfall in this area is 1068mm. Average maximum and minimum temperature is 42^0C and 2^0C.

LandSAT FCC (Band 4, 5, 7) and SOI Topsheets (53G13 and 53K1) are used in this study. MATLAB has also been used to develop programs for Maximum Likelihood Classifier (MLC) and Fuzzy Maximum Likelihood Classifier (FMLC).

METHODOLOGY

The factors affecting HSC are varied and large in number. Due to limitation in field experiments, measuring capabilities and spatio-temporal variations in the soil properties, the measured parameters show uncertainty. Uncertainty in measured parameters, in turn causes uncertainty in soil classification. In order to remove this uncertainty use of fuzzy logic is an only alternative, as fuzzy logic is helpful where parameters show uncertainty [43]. Keeping above in view this study has been carried out in the following steps:

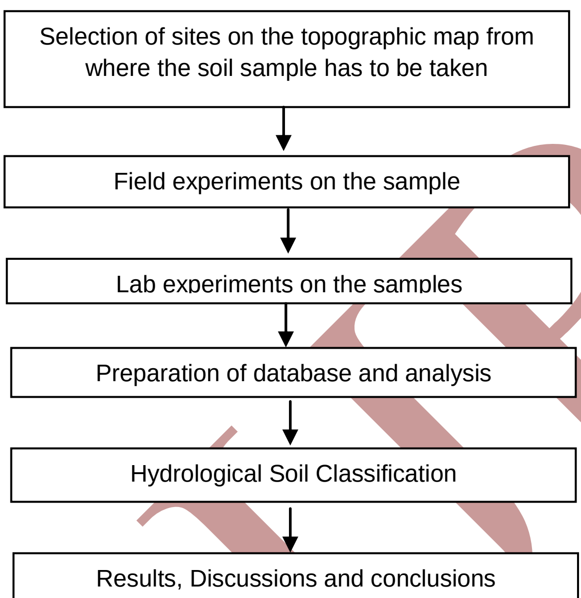

Fig.1 Methodology of Research

In order to evaluate various soil parameters required for HSC extensive field surveys and laboratory experiments were carried out. Before conducting field surveys, sampling sites were selected. For this topographic maps (53G13 & 53K1) and False Color Composite (FCC) were used. These sites were selected keeping in view the accessibility and spatial variation in soil properties. Although initially 26 sites were selected for sampling, but only 20 samples could be obtained. For conducting the lab experiments, soil samples of approx. 3 kg were collected from each site in polythene bags and properly labeled.

During field traversing, field experiments were carried out to estimate infiltration capacity by Infiltration test and effective depth of the soil by auger drilling, local enquiry and observing the soil profile along the river. Lab experiments were carried out in order to determine the grain size distribution of soil, Soil Permeability and its clay content. An attempt was also made to evaluate these parameters using spectral reflectance of the soil.

Soil samples collected during field traversing were subjected to sieve analysis as described in Soil Mechanics and Foundation Engineering (27). After this, hydrometer analysis was carried out to determine clay percentage. In similar manner, test was performed for all the soil samples. Permeability of the soil was determined with the help of a variable head pemeameter. Since, Remote Sensing techniques have proven capability to provide many of the parameters required for soil surveys (23), thus, in the present study, an attempt has also been made to estimate some of the parameters required for HSC from spectral response of soil. The grain size distribution curve are plotted for all the observations and curve for a sample set of observations is shown in Fig 1.3. From the grain size distribution curve (Fig 1.3) d50 for each soil has been determined. Relationship between d50 and spectral response were studied through graphical analysis. Graphs between d50 and spectral response at 0.4µm to 1 µm prepared (Fig 1.4). Out of these graphs the relationship at 0.4µm and 0.5 µm were found to be more representative.

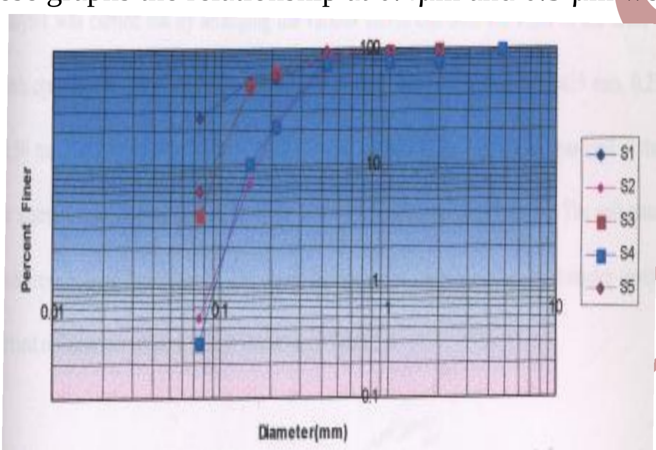

Fig.2 Grain Size distribution curve for a sample set of observation

An attempt was also made to compare the developed relationship between d50 and reflectance with the Orlov's (1988) equation i.e $R=R_{\infty}+K-10-nd$, where R is Reflectance, d is effective diameter and R_{∞} is reflection coefficient of aggregates of max, diameter, K and n are constants. At 0.4µm the numerical values of R_{∞},K and and n are 0.01, 1.0, 1.6 respectively, whereas at 0.5µm these values are 0.2, 0.9, 1.5. Values obtained from observed and computed values are shown in Fig 1.5 (a) and (b), for a set of observation. The relationship between soil reflectance at 0.5µm wavelength and d50 has been found to be close to the computed values using Orlov's equation.

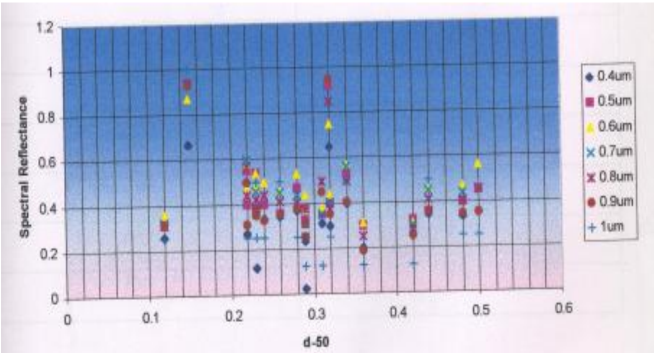

Fig.3 Graph b/w Spectral Reflectance at different wavelength at d-50 of samples

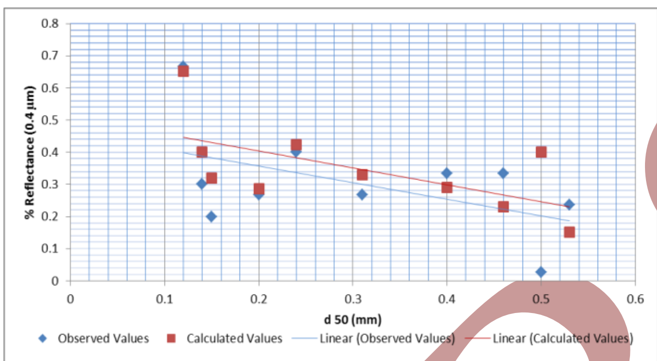

Fig.4 Graph showing comparison of observed and computed Reflectance at 0.4 µm

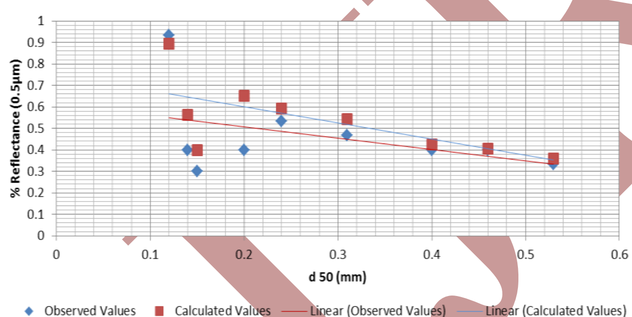

Fig.5 Graph showing comparison of observed and computed Reflectance at 0.5 µm

In this study HSC carried out by SCS approach, Maximum Likelihood Classifier (MLC) and Fuzzy Maximum Likelihood Classifier (FMLC). Later on, results and compared for each approach. In SCS Approach, Soil samples are classified into their respective classes based on SCS criterion, which are tabulated in Table 1.1. It is observed that on the basis of one property some samples are classified into one class, while on the basis of other property, they are found to be of some other class. This situation in existing is soil samples having ID No S6, S10, S12, S19, and S20. For this reason, it can be concluded that uncertainty exists in SCS approach.

Table 1 Hydrological soil classification based on SCS Approach

Soil Samples	Clay %age	Infiltration (am/hr)	Permeability	Effective	Remarks
S1	A	A	A	A	
S2	A	A	A	A	
S3	A	A	A	A	
S4	A	A	A	A	
S5	A	A	A	A	
S6	B	B	B	B	uncertainty
S7	A	A	A	A	
S8	A	A	A	A	
S9	A	A	A	A	
S10	A	A	A	A	uncertainty
S11	A	A	A	A	
S12	A	A	A	A	uncertainty
S13	A	A	A	A	
S14	A	A	A	A	
S15	A	A	A	A	
S16	A	A	A	A	
S17	A	A	A	A	
S18	A	A	A	A	uncertainty
S19	A	A	A	A	uncertainty
S20	A	A	A	A	uncertainty

In MLC Approach,

To remove the existing uncertainty as observed in Table 1.1, soil classification has been carried out by MLC. For this classification a program has been developed which is compatible in MATLAB. This program has been initially checked for already classified data from NIH reports (33,34). Based on the training data set, mean vectors and covariance matrices for each hydrological soil class has been calculated. It reveals that the mean value of clay percentage increases as Hydrological Soil Class changes from A to D. For hydrological soil Class A, it is having least numerical value of 4.6%, whereas for Class D it is maximum having numerical value of 52%. It has been concluded that if clay percentage increases, the run-off generating capability also increases. Similarly, it has been analyzed that Permeability, Infiltration, Effective Depth decrease as Hydrological soil class changes from A to D. Thus, it has been found that as these properties i.e. Permeability, Infiltration, Effective Depth decrease, the runoff generating capability increases.

Further, it has been observed that soil permeability and its infiltration rate are highly correlated. Thus in an analysis one of these may be omitted if so desired, in conformity with observations made in NIH reports. Although there are very large variations in effective depth, but if normalization of data would have been done, may be then variation would not be so much. Mean and covariance computed above were used in the program to classify a soil in Hydrological soil group. Results are tabulated in Table 1.2.order to remove this uncertainty use of fuzzy logic is an only alternative.

Table 2 : Mean Vector Based on Training Data

Hydrological Soil Classes	A	B	C	D
Clay	4.6	16.3	33	52
Permeability	14.7	5.12	3.19	0.77
Infiltration	19.5	7.8	1.14	0.79
Effective Depth	107.2	69.3	3.73	13.4

Table 3: Covariance Vector Based on Training Data

Factors	**Clay**	**Permeability**	**Infiltration**	**Effective Depth(c)**
Clay %age	4.2667	2.8667	3.444	6.0889
Permeability	2.8667	22.233	22.833	2.622
Infiltration	3.444	22.833	23.833	3.111
Effective D	6.0889	2.622	3.111	48.400

FMLC also has been used for hydrological soil classification. Steps for the FMLC which are adopted in this study are shown in figure 1.6.

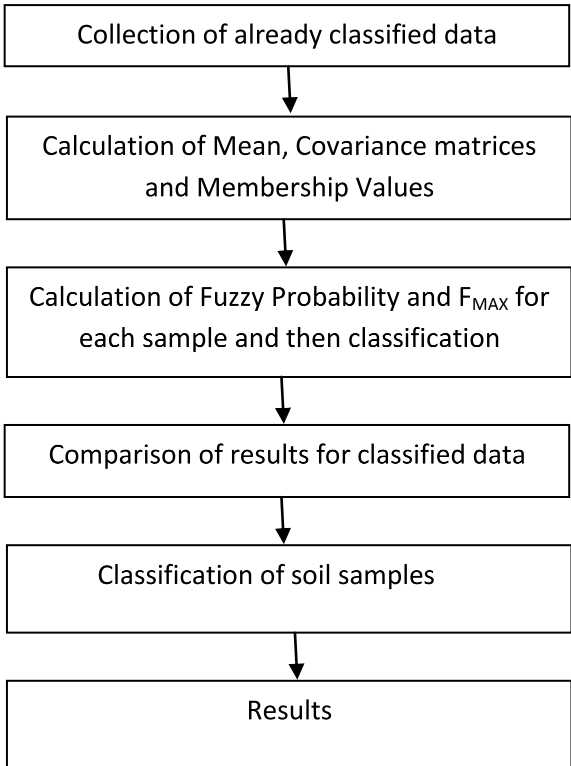

Fig.6 Steps for FMLC Approach

For classification of soil, required data i.e. Effective depth, Infiltration Rate, Permeability, Clay percentage have been considered as considered earlier. First of all, a diagram representing variation in these parameters as fuzzy variable for each hydrological soil group has been drawn, which assumes that soil boundaries are not crisp or sharp as assumed in MLC. Based on this, membership functions for each hydrological soil class group have been developed. Then, these membership functions are further used for the hydrological classification of soils, with the help of program developed, which is compatible on MATLAB. Results are tabulated for this approach in Table 4

Table 4: Covariance Vector Based on Training Data

Soil Samples	HSC based on MLC	HSC based on FMLC
S1	A	A
S2	A	A
S3	A	A
S4	A	A
S5	A	A

S6	B	B
S7	A	A
S8	A	A
S9	A	A
S10	B	B
S11	A	A
S12	B	C
S13	A	A
S14	A	A
S15	A	A
S16	A	A
S17	A	A
S18	A	A
S19	B	B
S20	B	B

RESULTS AND DISCUSSION

The results of the Hydrological Soil Classification by different approaches are tabulated in Table 1.1 and Table 1.3. Graphical analysis of Figure 1.6a shows that while using MLC approach, 75% of the area belongs to Class A, 25 % of the area in Class B and no area in found out to be in Class C as well as in Class D.

Analysis of Figure 1.6b also shows that whole study area is covered with three classes i.e. 75% of the area is in Class A, 20% of the area is in Class B and rest of the area belongs to Class C. Results are discussed as below:-

a) It has been observed that uncertainty prevails using SCS approach for HSC. In SCS approach, when all the factors are used in decision making, it creates confusion as to which class a soil belongs. No definite conclusion can be drawn, while using this approach. Thus there is a need of a different and new approach, which can remove this uncertainty.

b) An attempt has also been made to estimate various parameters i.e. Clay percentage, infiltration, grain size, permeability by using Remote Sensing data. Graphs were provided, which shows the relationship between spectral reflectance with clay percentage, infiltration and grain size.

c) MLC gives better results, as it accounts for all the factors influencing HSC. But MLC assumes crisp soil boundaries.

d) Uncertainty can be eliminated in FMLC. Results of FMLC were found to be in agreement with ground conditions

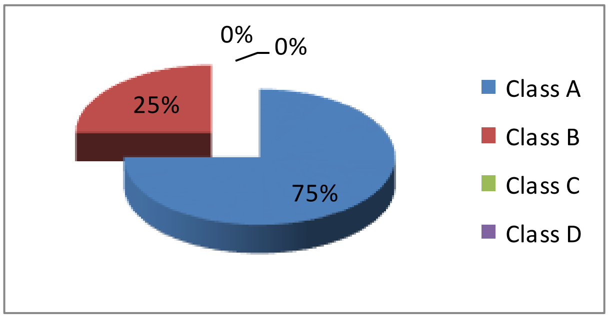

Fig.7 Hydrological Soil Classification using MLC

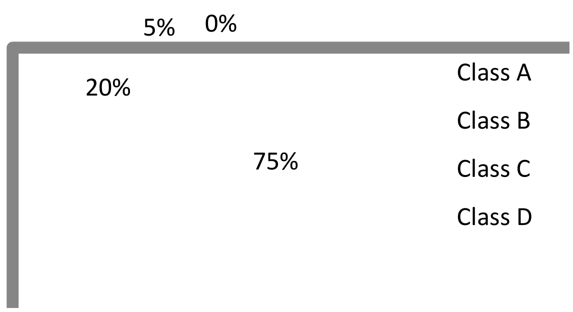

Fig.8 Hydrological Soil Classification using FMLC

CONCLUSIONS

Following conclusions can be drawn from this study:
a) Fuzzy approach is more reliable and dependable for HSC
b) Remote Sensing can be successfully used for extracting relevant information.
c) It has been observed that HSC depends on land use, slope, aspect and agricultural practices and can also be taken into consideration for HSC.

SCOPE FOR FUTURE STUDY

The study has been done only for limited area due to limitations of time. The study could be extended to much bigger area and may be used to classify the soils at national or international level.

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