CHAPTER – 4

ESTIMATION OF LAND POTENTIALITIES

4.0 Introduction

Scientific uses of land, its potentialities are very important. Potentialities of the land area used in specified ways or with particular management practices. Not only that, land evaluation is the process of estimating the potential of land for alternative kinds of use. These include productive uses, such as arable farming, livestock production, and forestry, together with uses that provide services or other benefits (Dent and Young, 1981). The main objectives of this chapter are to discuss the land evaluation for land capability and suitability of agricultural land in the district.

4.1 Land evaluation

Land evaluation is generally defined as "the measurement of land performance when used for a particular purpose, relating the execution and investigation of surveys and studies of landforms, soils, vegetation, climate and other characteristics of the land in order to identify and make an assessment of promising kinds of land use in terms applicable to the objectives of the evaluation" (FAO, 1976). The land evaluation procedure is involving interpretation of basic data to afford ratings of relative suitability of few socially and economically promising, physically thinkable land use alternatives (Brinkman and Smith 1973). The principal objective of the land evaluation is to select the optimum land use for each defined land unit taking into account both physical and socio-economic factors and conservation of environmental resources for future use. Detailed objectives vary considerably according to the principle and measure of the land evaluation (Sys, et al, 1991). Land evaluation result classifies and groups of the land based on their capability and suitability situation and it helps future improvement of the land for better land use potential by selecting suitable measures.

4.1.1 Land capability

Generally, Land Capability Classification (LCC) depicts the suitability of land for agriculture and other uses, wherein the land is categorised considering the number of soil characteristics, connected land structures and environmental influences viz, climate (Nema, et al, 1999). But land capability classification is a field investigation of soil properties, slope, degree of soil erosion and changing land use patterns which form the basis for future planning of soil conservation (Sharma, 1972). Land capability arrangement is a scientific assessment of the physical characteristic of land, its inherent soil qualities and the farm administration practice. Land capability maps established on the local units thus surveyed delineate problematic and possible arable lands approachable to the use of bio-chemical processes and to fluctuating volumes of farm administration practices (Singh and Dhillon, 2005).

4.1.1.1 Factors of land capability

The land is the most important resource for mankind. According to Bouma (1996), soil quality as a particular attention of land characteristics values, which should be enhanced be mentioned to as FAO style land virtues such as workability and erodibility. He also highlighted that the soil quality is well-defined without reference to an exact land utilization type, discounting one of the important principles of the land evaluation approach. In the present study main factors namely; type of terrain, annual rainfall (mm), temperature (^{o}C), irrigation area (%), drainage condition, predominant soil types, slope (degree), availability of soil nutrients (NPK) and availability soil moisture are selected for the measurement of land capability. The type of terrain is an important factor for land capability classification. There are two types of terrain character are found in the district. Out of 9 C.D. Blocks, 4 blocks namely Chopra, Islampur, Goalpokher-I and Goalpokher-II terrain character is slightly undulating and rest blocks have plain terrain character. Plain terrain character is suitable for crop production because modern agriculture inputs (irrigation, tractors and harvesters) are smoothly working on it. The average annual rainfall ranges from 2068.50 mm to 1453.12 mm and spans seven months (April to October). The areas of highest rainfall lie in the southern part (Kaliaganj Block-2068.50 mm) and lowest in the northern part (Goalpokher-I & Goalpokher-II- 1422.95 mm) of the district. Temperature modifies the local climate of a place. The average temperature values range from 25.14^{o}C to 26.60^{o}C. These values are comparatively suitable for crops. The highest temperature is found in Karandighi Block (26.60^{o}C) which is located in the central part of the district and the lowest is found in Raiganj Block with 25.14^{o}C. Another important factor is irrigation. The main irrigation sources in the district are canals, shallow tube-wells, river lift etc. Canal irrigation is mainly found in two blocks namely Chopra and Kaliaganj. Block-wise highest irrigation area is found in Kaliaganj Block (covered 72.83 per cent) and the lowest is found in Goalpokher-II Block (covered 53.55 per cent of the total area). The drainage condition in the district is very well to moderate. These conditions are suitable for agriculture as well as crop production. Soil types come next to drainage. Soil type’s condition is old alluvium to new alluvium and most of the blocks namely Chopra, Islampur, Goalpokher-II, Karandighi, Raiganj and Itahar fall under the alluvium category. But two blocks namely Hemtabad and Kaliaganj falls under the old alluvium category and only one block namely Goalpokher-I soil falls under new alluvium category. The slope is a very important factor for determining land capability classification because of the above 4° slopes. In the district, Chopra, Islampur and Goalpokher-I Blocks land are sloppy. Sloppy slopes are dis-advantageous due to the increased erosive power and are not smoothly accessible for any agricultural activities. The rest of the blocks have a slope under 4 degree which is a comfort for farming activities. Available nutrients like total N ranges between 284.42 kg/ha to 413.80 kg/ha. But available P in the soil ranges between 136 kg/ha to 235.60 kg/ha. The lowest is located in Goalpokher-I Block and the highest is found in Islampur Block. On the other hand, available K present in the soil ranging from 175.83 kg/ha to 293.60 kg/ha in the district. Availability of soil moisture is most useful for land capability evaluation and management as it provides information about the amount of water present in soils and thus potential availability for crops subsequently the land capability for specific crops. In this way, the association of all the factors summarizes has helped to land capability classification of the district (figure 4.1).

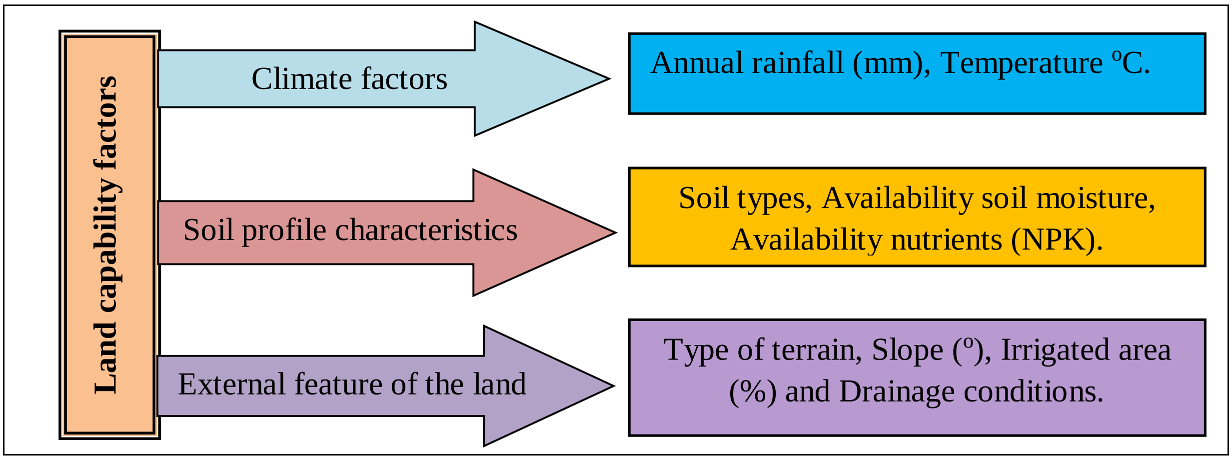


Figure 4.1 Factors of land capability classification.

4.1.1.2 The USDA method of land capability

The type of land capability classification is usually known as the USDA method of land classification. Actually, it was the soil conservation movement of the 1930s. The method was first noticeable by Hockensmith and Stele (1949). But a full explanation of the land capability arrangement was published in 1961 (Klingebiel and Montgomery). This scheme is based on the conception of limitations on land use forced by land quality. There are I to VIII classes for the land use classification and among of them Class I type of land, there are no limitations for cultivation while Class VIII several limitations are harsh.

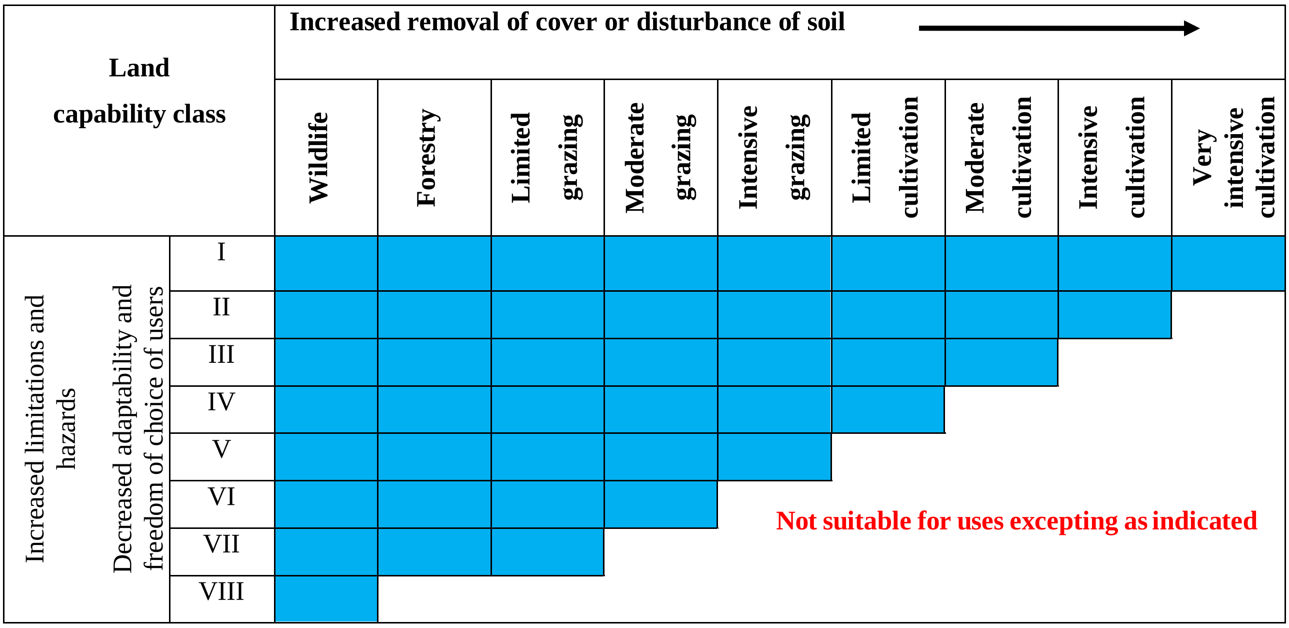


Figure 4.2 USDA land classification: correlations connecting permanent land restrictions and safe land use.

Source: Hockensmith and Steele, 1949

4.1.1.3 Construction of land capability classification

In land capability classification three categories are recognized i.e. land capability class, capability subclasses and units. Land capability classes are represented by roman numerals and limitations on types of land use increasing from class I to class VIII. Construction of land capability classification as well as capability class, capability sub-classes, and capability units are presented in the table 4.1.

Table 4.1 Represents construction of land capability classification.

Capability class		Capability subclass	Capability unit	Soil mapping units
Arable land	I	--	--	--
	II	IIe, erosion → IIw, wetness IIs, soil IIc, climate IIes, etc.	IIe-1 → IIe-2 IIe-3 etc.	P series Q series R series
	III	--	--	--
	IV	--	--	--
Non-arable land	V	--	--	--
	VI	--	--	--
	VII	--	--	--
	VII	--	--	--

Source: Dent and Young, 1981

Total capability classes are distributed into two broad categories: classes I to IV fall under arable (suited for cultivation) land but classes V to VIII under non-arable (not suitable for cultivation) (table 4.1). Not only that, classes I to IV can easily be thought of as very good,

good, moderate and marginal arable land and rest classes V to VIII, class V is unsuitable for agriculture, class VI can be managed under improved pasture, class VII is only appropriate for grazing and class VIII type is not used for commercial plant production.

Capability sub-classes represented by alphabetical suffices i.e. indicate the type of limitations encountered within a class. Capability sub-classes are-

e = erosion hazard, **w** = wetness or excess water,

s = soil factors such as stoniness and **c** = climatic limitations.

Capability sub-classes are not only four in number, sometimes the number of capability sub-classes have been increased. Under the capability lies the classification of sub-class under which lies the capability units. The unit has a small difference in the type of limitation and is appropriate for similar crops under similar farming sectors. It will be evident that altered types of soils may be grouped in a similar capability class if the level of limitation is constant. In this way, any differences among soil mapping components that are of no significance in management are removed by the grouping into capability units. Units are given by the Arabic numbers e.g. IIe-1, IIe-2 and IIe-3 etc. (Dent and Young, 1981).

4.1.1.4 Limitations of each land capability classification

The land capability classification method is a schematic representation of different types of land to produce on a long time basis. It is summing up of the suitability of land for its production function. But some lands have limitations for the growth of suitable crop production. These are discussed in table 4.2.

4.1.1.5 Building fuzzy logic in capability

a. Conventional and evaluation process

As discussed earlier, land evaluation process mentioned in this study is according to the agricultural crop requirements. These conventional systems differ in the way a final land index or score is measured (table 4.3). The score is used to find out the land capability classes of the lands. In the study, eleven dependent variables are used as input variables i.e. type of terrain, annual rainfall (mm), monthly temperature (^{o}C), irrigation area (%), drainage condition, soil types, slope (^{o}), available nutrition status (NPK) and soil moisture which are important to the determination of land capability classes in the study area.

Table 4.2 Summary of limitations of each land capability class.

Land capability class	Broad groups	Limitations of lands
I	Suitable for cultivation	Very insufficient limitations and it is a very decent land which suitable for all crop production. Moderately sloping, easily workable soil and slightly acid soils.
II		Normally good land and moderate boundaries for use. The slope character is moderately sloping.
III		Simple limitations for crop production. Systematic crop cultivation is possible if provisions are made against the hazard. Slope character is may be steep.
IV		A very simple limitation for use and it is suitable for irregular cultivation. The slope situation may be steep.
V	Not suitable for cultivation	This class land is not suitable for cultivation because of the absence of wetness, dryness and texture, etc. But there are insufficient restrictions on its use as grazing and forestry purpose.
VI		This type of land is not suitable for good farming. Because land may be very steep, dry, wet situation. Although, occasionally use for grazing and forestry purpose.
VII		The land is also not suitable for agriculture. Because land varying from steep to almost vertical slopes. Shallow soil, thrilling dryness, and wetness. It is also used for grazing and forest purposes.
VIII		A very bad situation such as very rough, wet and dry condition, etc. prevails on this land for its use in crop production. Not only that, it is used for limited wildlife preservation purposes.

Source: Negi, 1983

Table 4.3 The input variables and respective classes for land capability classes based on different factors.

Different factors		Capability class and rating scale				
		Class-I	Class-II	Class-III	Class-IV	V-VIII
Type of terrain		Plain	Slightly Undulated	--	--	--
Annual rainfall (mm)		>1853.31	1636.13-1853.31	<1636.13	--	--
Monthly temperature (°C)		<25.63	25.63-26.12	>26.12	--	--
Irrigation area (%)		>66.41	59.98-66.41	<59.98	--	--
Drainage		Very well	well	Moderate	--	--
Soil types		New Alluvium	Alluvium	Old Alluvium	--	--
Slope (°)		<3.750453	3.750453-4.184757	4.184757	--	--
Nitrogen	Available nutrition status	>370.68	327.55-370.68	<327.55	--	--
Phosphorus		>196.20	156.81-196.20	<156.81	--	--
Potassium		<215.09	215.09-254.35	>254.35	--	--

Soil moisture	>79.61	70.18-79.61	<70.18	--	--

Source: Compiled by the researcher.

b. From classical set theory to fuzzy set approach

The fuzzy set (classical) theory originally proposed by Zadeh (1965), was developed to deal with clumsily defined expressions, classes e.g. 'significant' or 'less significant'. The force of the fuzzy logic to become an appropriate tool for a societal researcher is capable to change the primary field statement classes like significant is '0' and less significant is '10'. In the classical set theory manage this fact as an observation (X) either belongs to a set A or not:

$$(x \notin A) \text{ or } (x \in A)$$

The similar membership function only takes two values i.e., 0 (($x \notin A$)) and 10 ($x \in A$). Not only that, the value A (x) is represented as "degree of membership". On the other hand "degree of belonging" can be represented as "membership function". But the amount of belonging of a land capacity can be expressed '0' and '10'. A ranst, as well as a fuzzy set A_X mapping from A to the unit interval (0, 10), is expressed as (Tang, et. al., 1996):

$$(A_x \in A) \ \ (A\ (x) \in [0, 10])$$

4.1.1.6 Input variable

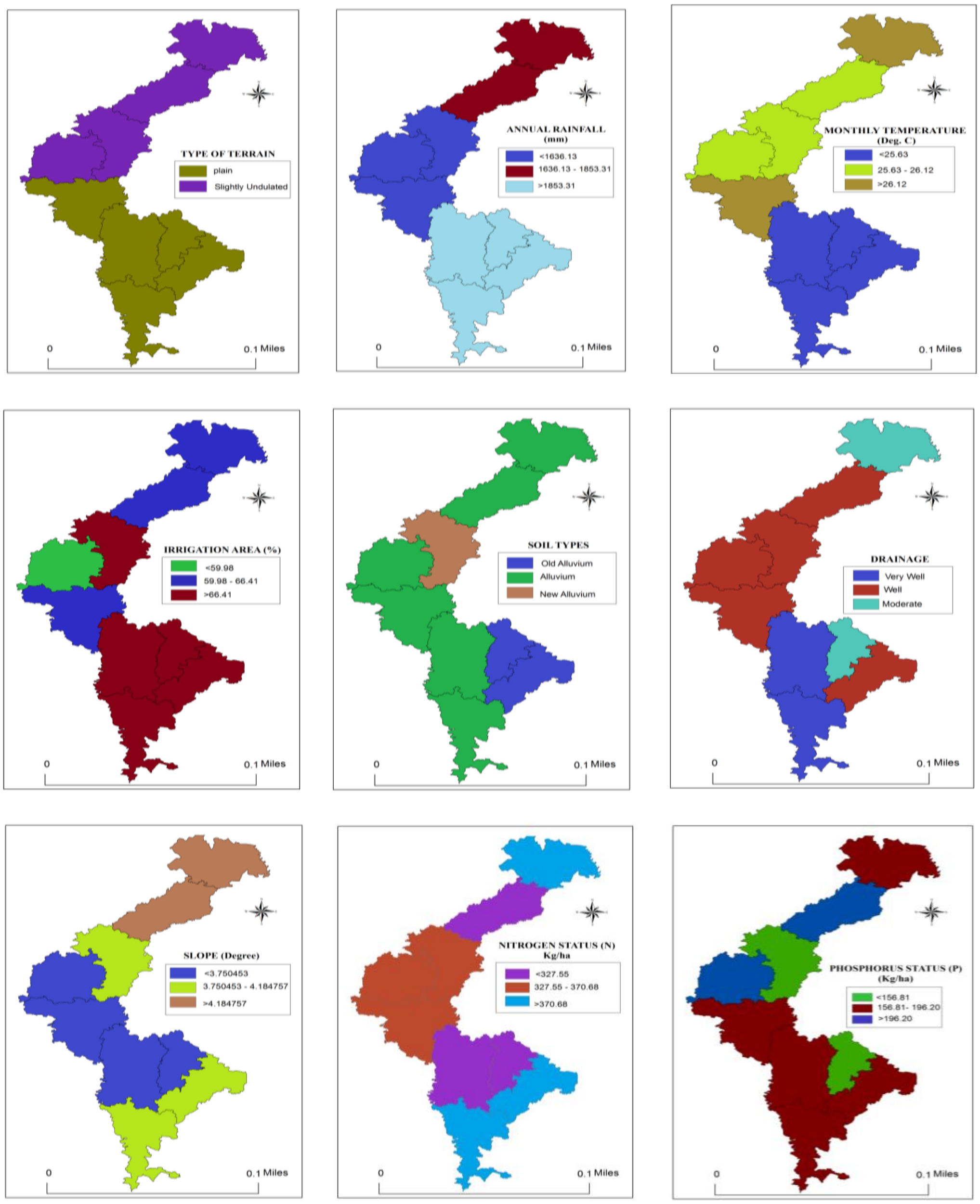
Different factors for land capability and having the degree of the spatial link are considered as the effort variables in fuzzy logic. All of these factors are not similarly relevant to the different places in the district. The measurement of capability of land spatially over the study area is done through three sets of variables such as (1) Soil profile characteristics (variables: soil texture, available nutrients status (NPK)); (2) Climate parameters (variables: annual rainfall and temperature); and (3) External parameters (variables: type of terrain, irrigation, drainage, slope and availability of soil moisture) which form the emphasis as the essential factors of land capability classification (Mandal, 1990; Dent and Young, 1981; Negi, 1983 and Mather, 1986). Considering the factors as previously examined in different studies in the different part of India and contrasting them with the scenario of the Uttar Dinajpur District is significant.

The present study could finalize three main factors and its eleven sub-factors having a proper influence on land capability. Not only that, one suitable indicator for each factor (i.e. eleven variables) was used as the input variable for the fuzzy logic models. In the study, eleven dependent variables are used as input variables i.e. terrain character, temperature, annual rainfall, soil types, nutrition status (NPK), irrigated area, drainage condition, slope and availability soil moisture which are explanatory to the determination of capability classes in the study area. Land qualities of each land unit in Uttar Dinajpur District are shown in table 4.4 (Appendix IV).

4.1.1.7 Assigning fuzzy membership functions

Fuzzy membership gathering expresses the degree value of a variable, having the likelihood to influence the result of land capability class. In this study, a membership function has been assigned as 'gauss' (i.e. Gaussian) in MATLAB's function editor input variables. In this way, the output variable has been assigned the 'triangulation features' (i.e. defuzzified) membership functions (figure 4.4).

Input layers in fuzzy interface system for generating land capability map



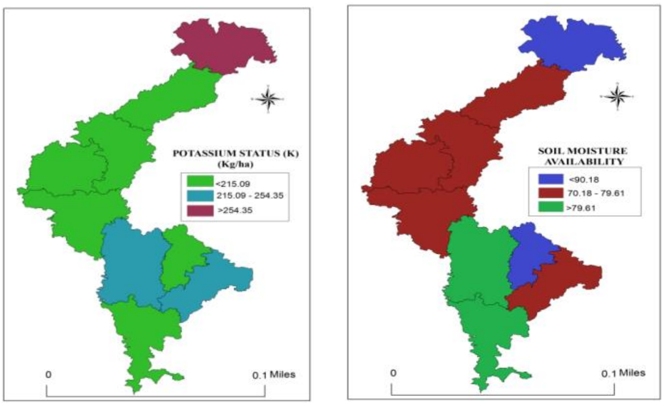
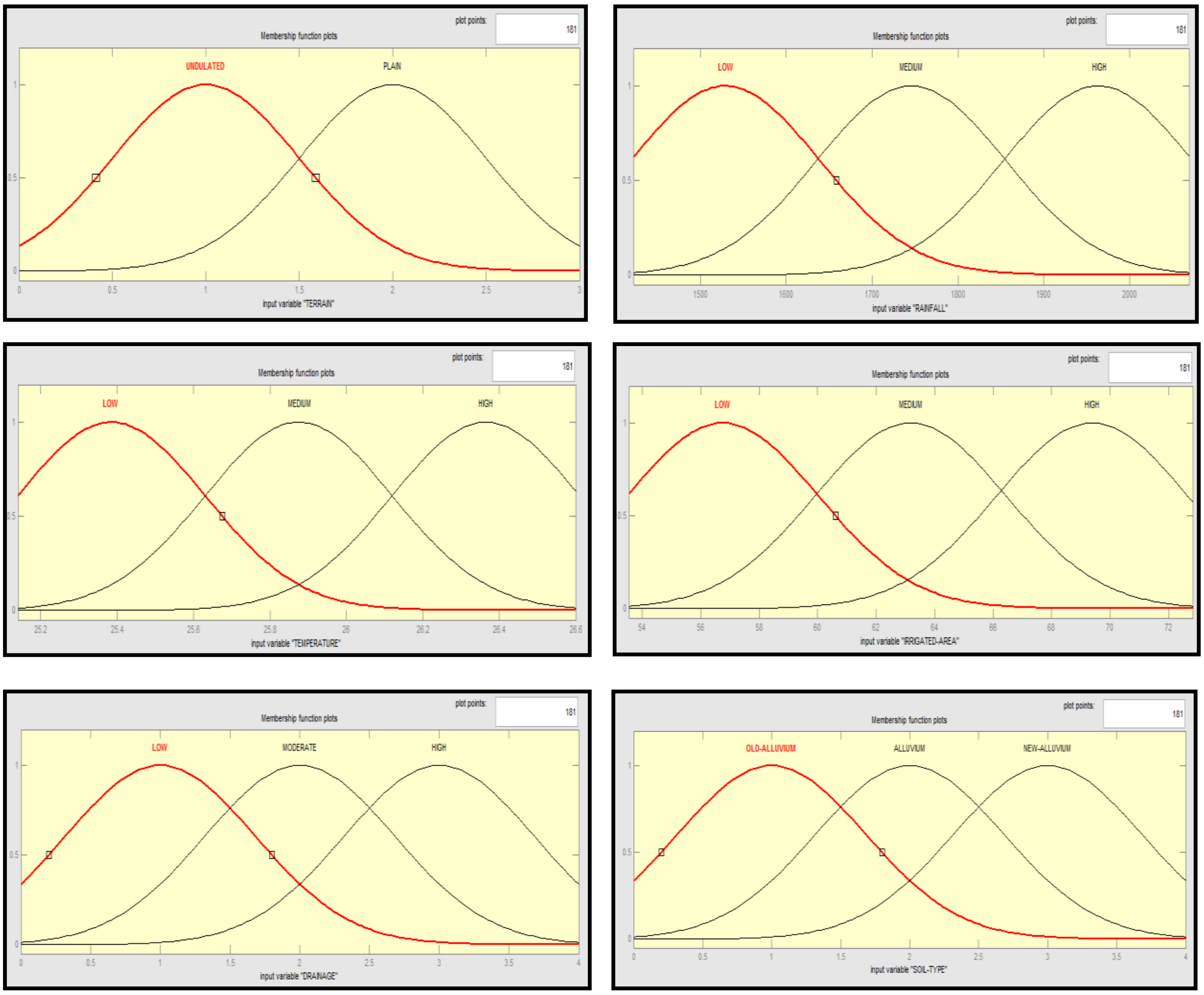
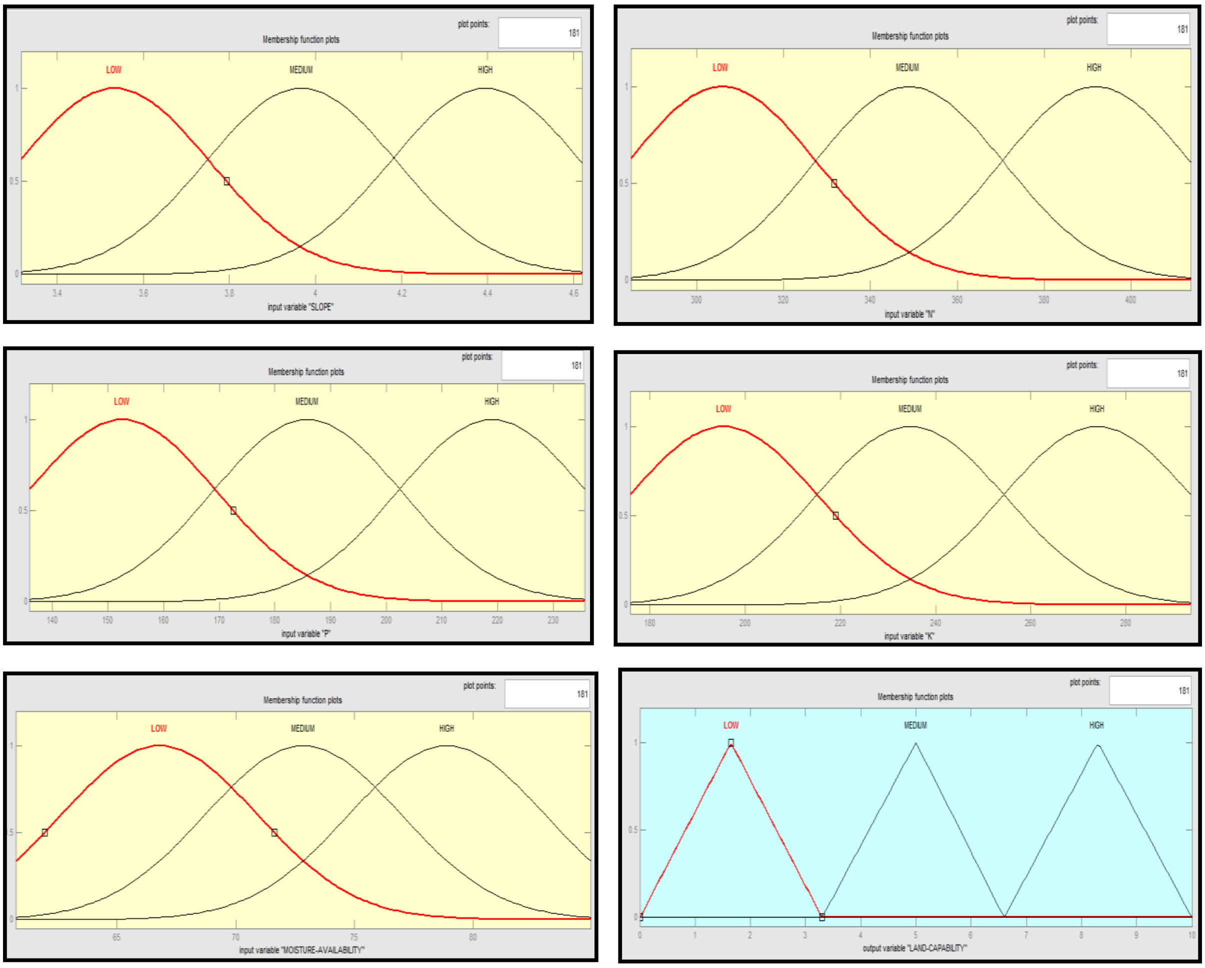


Figure 4.3 Input layers in fuzzy logic of different variables.

4.1.1.7.1 Initial rules to link input variables with the output results in a fuzzy model

Selected factors for land capability and having the degree of the spatial link are considered as the effort variables in fuzzy logic. All of these factors are not similarly relevant to the different places in the district. Climate factors like; annual rainfall (mm) and temperature ^{o}C have been emphasis as the important factors of land capability classification.





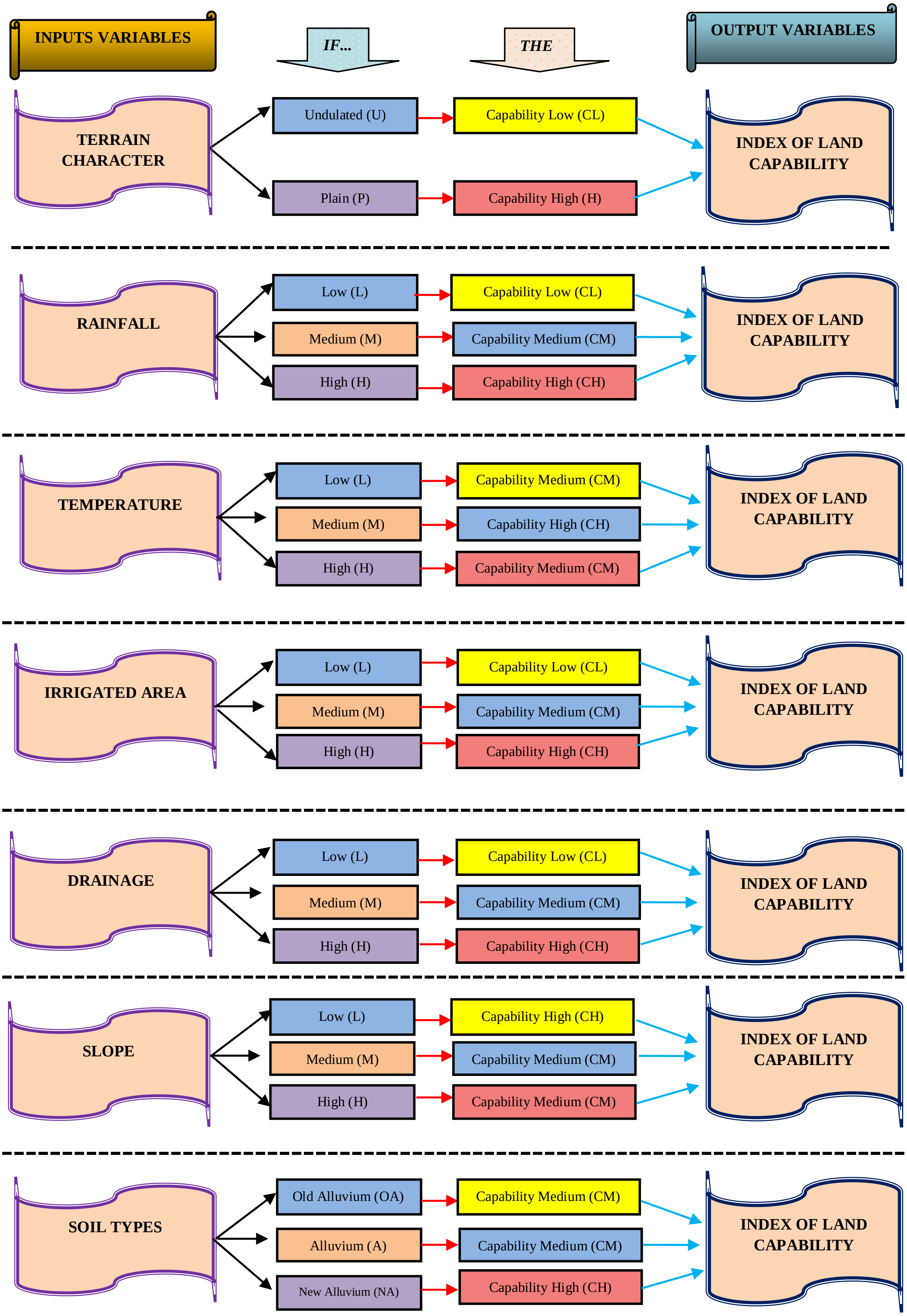
Note: All membership (11 variables +1final land capability output plots) plots are sereen printing features from MATLAB 17 Software.

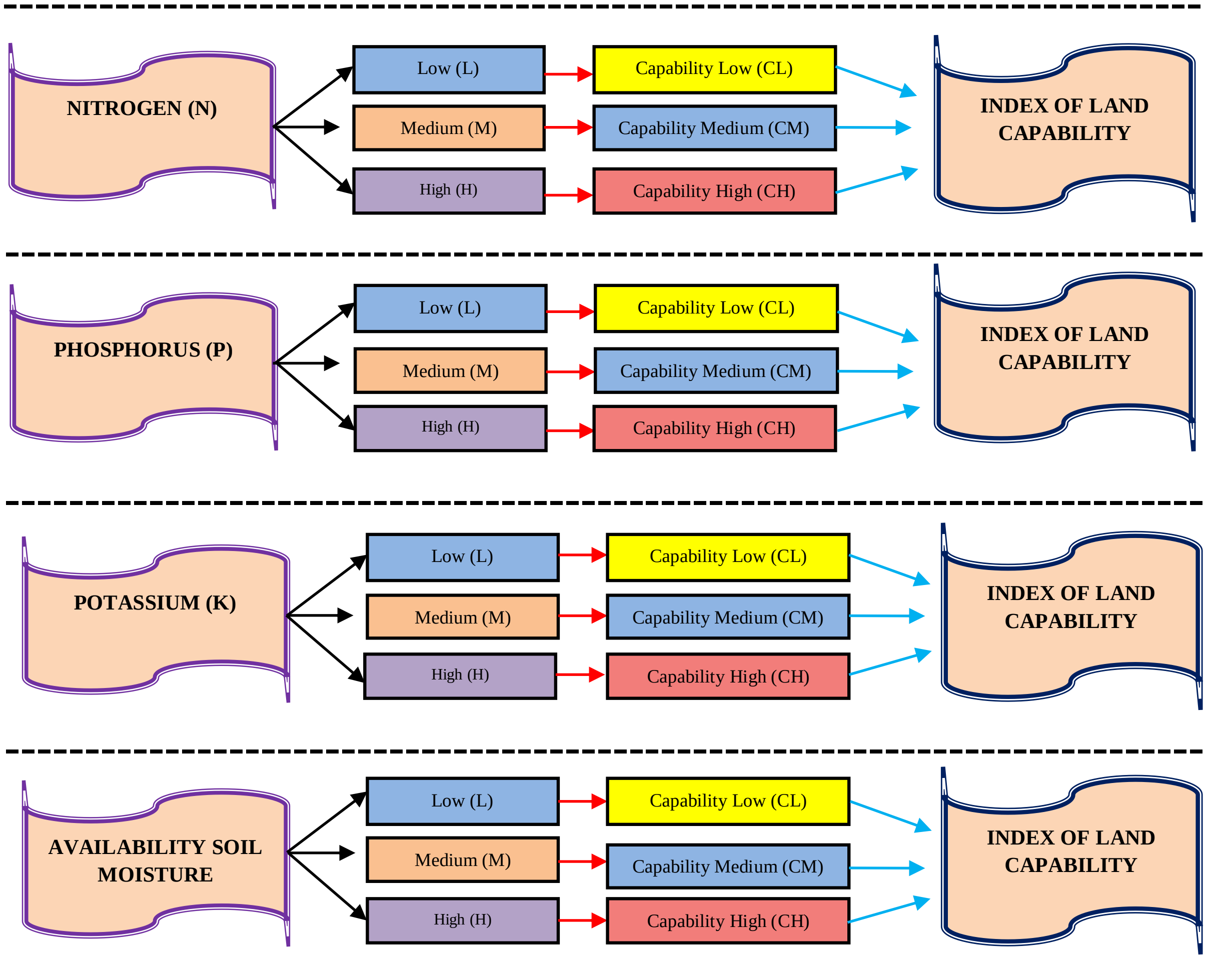
Figure 4.4 Fuzzy membership functions of all input and output variables.

Soil profile factors like; soil types, availability of soil moisture, availability of nutrients (NPK) and external factors like; types of terrain, slope (°), irrigated area (%), drainage condition (Mandal, 1990, Oluwatosin, et al, 2006 and Singh and Dhillon, 2005). Soil quality assessment can be made to help identify areas where problems occur, identify areas of special interest or compare land under different management systems. Not only that, soil quality data can be used by landed capability management choices (USDA, 2001).

4.1.1.8 Fuzzy classes for the output variable

The result of concluding land capability classification obtained using fuzzy logic is further disaggregated into three classes, namely 'high capability, 'medium capability' and 'low capability' for land capability classification (figure 4.5). The extreme score will be very capable land for agricultural purpose and the lowest scores will be the low capability land for farming purposes.





Source: Compiled by the researcher.

Figure 4.5 Graphical representation of different variables used in a fuzzy editor for connecting inputs variables with output variables.

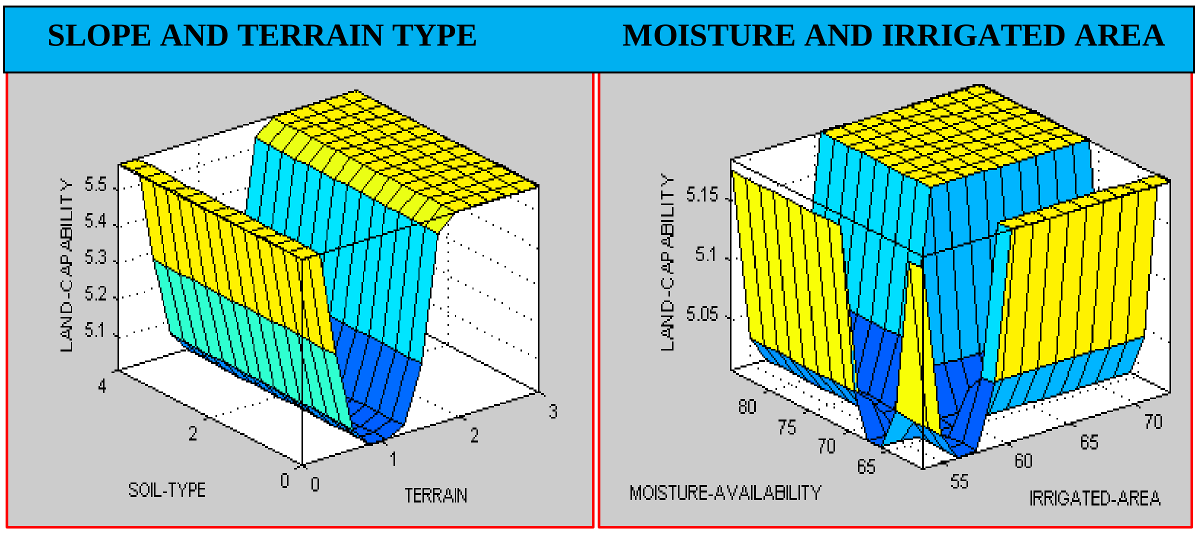


Figure 4.6 Representation of the result of weight assigned as a different scale to the different variables.

The land capability of agriculture can be used as a point for land use choice-making. A possible classification of land capability for agriculture is shown in table 4.5. In this study, there has been entire liberty to set the output range in the fuzzy model for the proper output has to be used for better mapping and the fuzzy output was set to the range between 0 to 10.

Table 4.5 The output variable and respective classes of land capability.

Variables	Low Capability	Medium Capability	High Capability	Total
Index of the land capability	<3.33	3.33-6.66	>6.66	3 Category
Total area (ha)	48,082	226,866	39,052	3,14,000.00
Percentage (%)	**15.31**	**72.26**	**12.43**	**100.00**

Source: Computed values compiled by the researcher.

i. Region of low land capability

The low capability class of land capability is in the district with a composite score of <3.33. This zone is determinate in the northern part of the district which accounts for 15.31 per cent of the total land area (figure 4.7). This category includes the block of Chopra with capability index (0.070596) and it's considered limiting factors are slightly undulated, annual rainfall 1761.1 mm, monthly temperature 26.23 ^{o}C, alluvium type soil; slope is above 4 degree, soil moisture 60.75 per cent which are not capable for properly agricultural use (mainly food grain crops). Not only that, this block constitutes the tea gardens, permanent pastures and other grazing land activities etc. But investment of huge capital, increased soil moisture continuous interval supply irrigation water can raise the capability index for grown the food grain crops.

ii. Region of medium land capability

Blocks having 3.33-6.66 land capability index (LCI) come under the category. It comprises the blocks of Islampur (3.970128), Goalpokher-I (6.426389), Goalpokher-II (4.584122), Raiganj (6.426389), Hemtabad (6.426389), Kaliaganj (5.827249) and Itahar (6.426389). In these blocks factors like soil moisture, sufficient amount of annual rainfall, suitable nutrition status, well drainage and slope condition below 4 degree are there which most affects the land capability index. The zone is located in the whole part of the district except northern and central part (figure 4.7) and this zone covers 72.26 per cent area of the district (table 4.5).

iii. Region of high land capability

Only one block namely Karandighi come under this zone and the capability value having 6.33 and above. The land capability index of this block is (8.746771). In this zone land capability index is high because type of terrain is plain, well drainage condition, alluvium type soil, suitable soil nutrition status and high soil moisture raising better crops production. Total 12.43

per cent area is under this zone of the district (table 4.5) and this zone is located in the central part of the district (figure 4.7).

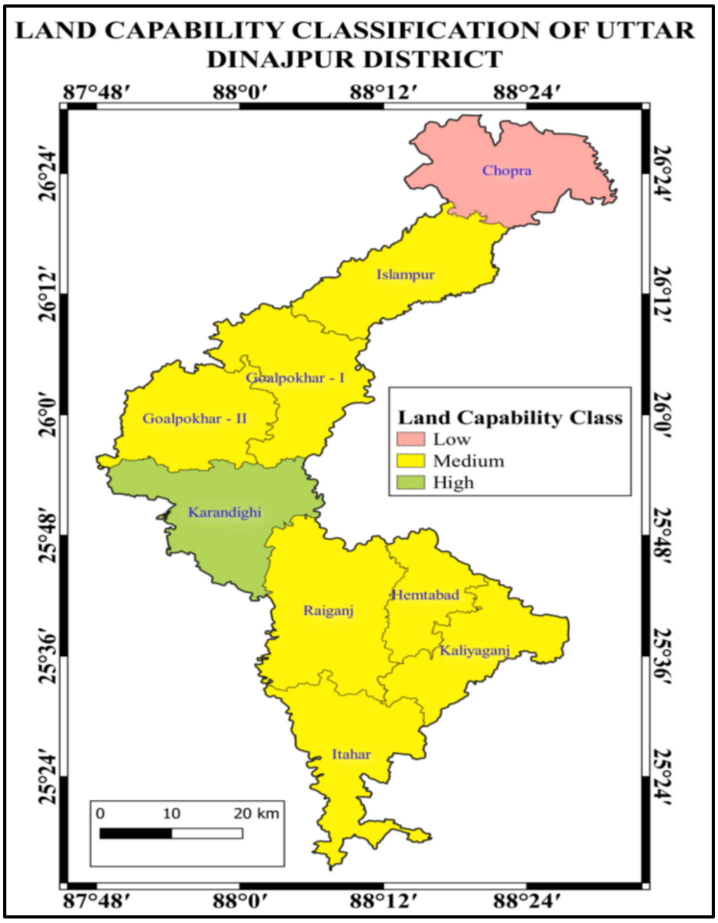


Figure 4.7 Land capability classification based on fuzzy logic in Uttar Dinajpur District.

4.1.2 Land suitability

Land suitability evaluation (LSE) is the method of assessing the suitability of land for a particular kind of use. These may be the most important kinds of land use (agricultural use). Each plant species requires exact soil and climate conditions for its optimal growth. In recent time agriculture demands more from the soil which is subjected to severe degradation through unsuitable management practices and use of chemical fertilizers and pesticides (Satish, 2010). But in the general term "Land Suitability Assessment" denotes to the examination of a certain part of land's appropriateness to exact types of land use. This assessment includes many influences that straight or indirectly control the ability of this portion of land to host the land use below examination. Performing land suitability assessment and producing maps of land suitability for different land use types will facilitate in reaching maintainable cultivation (Vargahan, 2011).

Now-a-days growing demands for increasing food grain production could be met through a methodical survey of soils and evaluation of their potentials for a broad range of land use options and formulating the land use policy. Not only that, land suitability classification is the method of appraisal and grouping of exact types of land in terms of their absolute or virtual suitability for a particular kind of use. Land suitability evaluation and agricultural land use planning are very essential and are the basic information for the right decision making afterward (FAO, 1993). The procedure of land appropriateness examination involved the assessment and grouping of areas of land in terms of their capability for a defined purpose. Land suitability evaluation is the prediction of the possible capacity of the land unit for a given use without deterioration (Rosa and Diepen, 2002). Land suitability assessment can be carried out on the basis of Bio-physical limitations and socio-economic situations of an area (FAO, 1976).

The FAO framework to the land assessment was used in the present-day study to know the consequences of applying the detailed management to the land. Also employed was alternative technique using fuzzy logic (Chang and Burrough, 1987) to determine the measureable influence of land qualities on agricultural production in Uttar Dinajpur District.

4.1.2.1 Recognition of evaluating criteria

A total of 50 sample land units defined according to topography, climate, and soil, etc. were selected for this study. Each component plays an important role in finding suitable conditions for agricultural crops produced in the district. In the study, a total of ten main criteria have been considered for agricultural land suitability namely; altitude, slope, CEC, clay, sand, silt, pH, drainage, water availability, and workability. An altitude is an important criterion for finding the land suitable sites. In high altitudes region modern agricultural equipment is not easily used. The slope is the important thing for the land suitability criterion, because in steep slope it is not easy to reach for any farming activities. But on the plain surface, farming performance is smoothly accessible due to the less soil erosion and depth of upper soil layer is high. If climatic atmospheres are positive, modest slopes are possible to have the maximum production of crops. The steep slope does not provision deep soil. Soil erosion difficulties are severe (Chinglianmawi and Singh, 2016). The availability of nutrients has been assessed with regard to the cation exchange capacity (CEC), p^H measured in soil. Soil p^H is another very useful thing in land suitability evaluation as it provides information about the potentiality and solubility of essentials for crops consequently the soil suitability for agriculture. Sand, silt, and clay are the best indicators for land suitability due to their ratio in the soil. If in a land area percentage rate of clay is high then the duration of water logging capacity of the soils is increasing. As a result, the non-water logging crops (jute, potato, maize, and wheat, etc.) cannot be properly grown. Oxygen availability has been assessed according to the drainage conditions. Water availability has been assessed according to efficient precipitation taking into account the loading capacity of the soil (Sinthurahat, 1992). Workability has been evaluated according to the texture, structure, moisture of the topsoil (0-20 cm). The value of these land qualities for each land unit is given in table 4.6 (Appendix IVa).

Keeping in mind the goal and objectives, the first element focuses on establishing a set of criteria and the second is to assign ranks to the criteria and alternatives. The overall suitability of soil was determined based on the degree and the number of limitations for a particular unit. The final land suitability was based on the number and degree of limitation. This map is cross-checked with the map of the land survey wings department of the district. Pre-field and post field ground truth verification for the thematic maps was cross-checked; updated and the final output was derived.

4.1.2.2 Land suitability assessment method

Generally, land suitability assessment is a multi-criteria problem, as the analysis of an evaluation problem concerning a number of parameters. Land suitability process can be summarized in a generic model as in the following function-

$$\mathbf{S = f\,(x_1,\, x_2\, ...x_n)}$$

Where, 'S' is suitability level and

x_1, x_2 ....x_n are the different factors for suitability.

The land suitability parametric element can be summarized in six steps as (figure 4.8) following the FAO framework for land evaluation. Two aspects are considered during this process. The first is the suitability score for each individual factor. After a score range is decided, a score can be assigned based on the attribute of a factor to reflect the suitability level. The coordinates of all the surveyed villages (will be mentioned as 'sites' in the following part of the study) were recorded with the help of a GPS handset for the purpose of plotting of the data with the GIS software platform (chapter I, figure 1.2).

4.1.2.3 Land suitability parametric approach

There are many assessment methods in land suitability mapping. But this work is interested in the parametric method i.e. can be summarized in six steps as in under (figure 4.8), following the FAO framework for land evaluation (FAO, 1976). Land qualities of each land unit in Uttar Dinajpur District are shown in the table 4.6 (Appendix IVa).

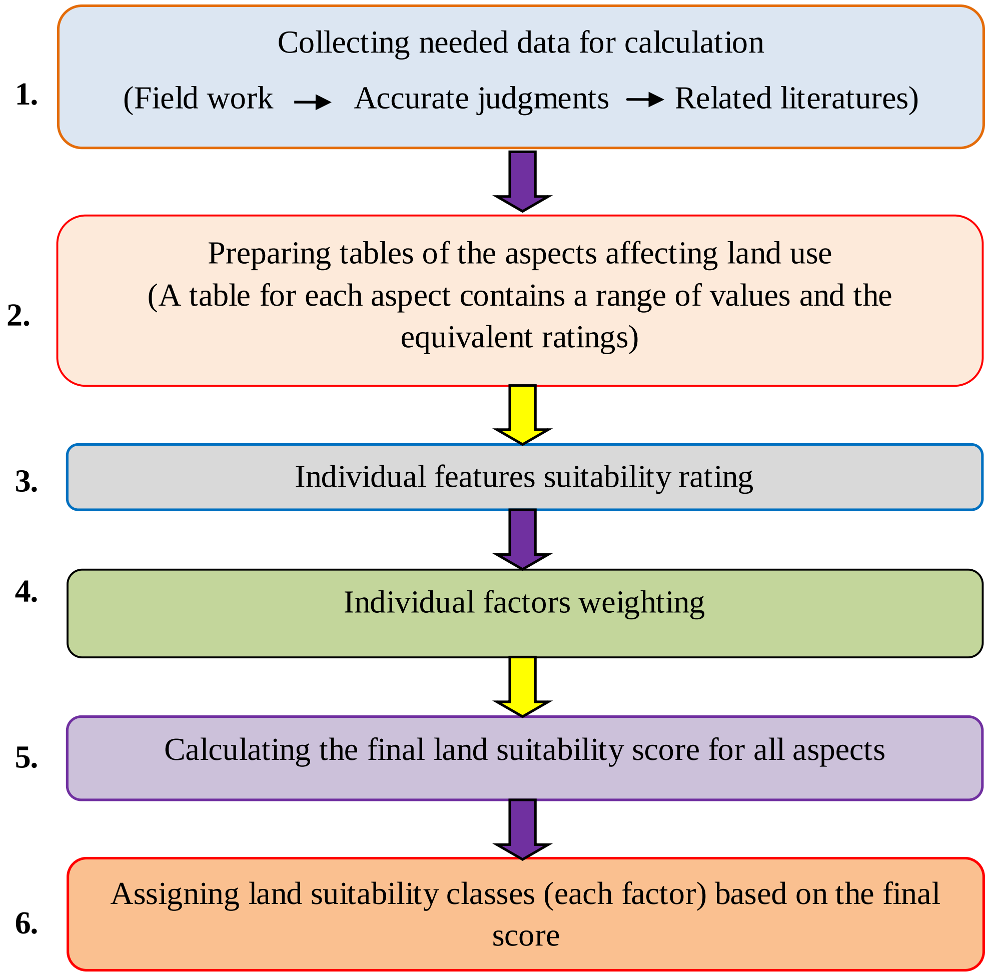


Figure 4.8 Flow chart of parametric approach procedure.

4.1.2.4 Construction of land suitability classification

Most of the plant varieties need water availability in soil, the average situation of soil texture, pH situation and having an optimum physical environment. Although selected plants may be found to progress under different soil and extreme agro-ecological condition, yet not wholly plants can raise on the parallel soil and under the parallel atmosphere (Mishra and Sahu, 1991). There are four categories of arrangement for land suitability in the FAO scheme; these are land suitability orders, classes, sub-classes and units (table 4.7). These suitability classes are measured distinctly for every kind of land use under consideration, with respect to all land mapping part in the investigation area (Dent and Young, 1981). The FAO land suitability classification system has four different categories of decreasing generalization which are recognized-

Table 4.7 Structure of land suitability classifications.

Categories			
(1)	**(2)**	**(3)**	**(4)**
Order	**Class**	**Sub-class**	**Unit**
S (Suitable)	S1	S2m	S2e-1
	S2	S2e	S2e-2
	S3	S2me	etc.
	S4	etc.	-
N (Not appropriate)	N1	N1m, N1e, etc.	Nil
	N2	-	-
NR (Not relevant)	-	-	-

Source: Dent and Young, 1981

From the above discussion, it is observed that there are three orders, one is ‘S’ and another is ‘N’ which return the category of suitability (‘S’ for Suitability and ‘N’ for Unsuitability of the land) and third is ‘NR’ which is not relevant.

1) Orders (Reflecting varieties of suitability)

(***‘S’*** – Suitable land)

Land on which continuous used of the category under thoughtfulness is expected to yield benefits that will validate the inputs without objectionable risk of damage to the land resource.

(***‘N’*** – Not Suitable land)

The land which has qualities that preclude continuous used for the kind under consideration which would create production, conservation problems requiring a stage of recurrent inputs unacceptable at the time of interpretation.

2) Classes (Reflecting amounts of suitability within orders)

There are many numbers of classes within each order. However, it has been recommended to use only 3 classes within order ‘S’ and 2 classes within the order ‘N’. Not only that, the class is represented by Arabic number in the sequence of decreasing suitability within the order and therefore reflects degrees of suitability within an order- i.e.

S1- Highly suitable, **S2**- Moderately suitable, **S3**- Marginally suitable and

N1- Generally unsuitable but potentially suitable, **N2**- All times not suitable,

NR- Lands which has not been assessed for a certain use.

3) Suitability sub-classes (Reflecting kinds of limitation within classes)

Suitability sub-classes indicate kinds of limitations, e.g. moisture deficiency, erosional hazard etc. there is no limit to the number of sub-classes symbols which may be employed in a particular survey. The sub-class symbols indicate a different kind of limitations and use some lower case letter symbols.

c- Climate, **a-** Altitude, **t-** Topographic limitation,

d- Drainage, **e-** Erosion hazard, **m-** Moisture availability,

f- Flood hazard, **n-** Nutrient availability, **f-** Soil fertility, etc.

4) Suitability units (Reflecting negligible differences in essential management within sub-classes)

This refers to land suitability sub-classes which differ from each other in full aspects of their management requirements. This can signify the relative significance of land improvement works. It is indicated successively, e.g. S2d-1, S2d-2, etc. There is no border to the number of units familiar within a sub-class.

4.1.2.5 Building fuzzy logic in suitability

a. Conventional and evaluation process

As discussed earlier, land evaluation process mentioned in this study is according to the agricultural crop requirements. These conventional systems differ in the way a final land index or score is measured (table 4.8). The score is used to find out the land suitability classes of the crops.

b. From classical set theory to fuzzy set approach

The fuzzy set theory proposed by Zadeh (1965), was developed to deal with clumsily defined expressions or classes (e.g. ‘significant’ or ‘less significant’). The strength of the fuzzy logic to become an suitable tool for a societal researcher is capable to change the principal field statement classes like significant is ‘0’ and less significant is ‘1’. In the standard set theory manage this fact as an observation (X) either belongs to a set A or not:

$$(\boldsymbol{x} \notin \boldsymbol{A}) \textbf{ or } (\boldsymbol{x} \in \boldsymbol{A})$$

The parallel membership function only takes two principles i.e., 0 (($x \notin A$)) and 1 ($x \in A$). Not only that, the value A (x) is characterized as “degree of membership”. On the other hand “degree of belonging” can be represented as “membership function”. However the degree of belonging of a land capacity can be expressed ‘0’ and ‘1’. A ranst, as well as a fuzzy set A_X mapping from A to the unit interval (0, 1), is communicated as (Tang, et al., 1996):

$$\mathbf{(A_{\mathit{x}} \in \mathit{A})\ \ (A\ (\mathit{x}) \in [0, 1])}$$

4.1.2.6 Input variable

Different factors for suitability and having the degree of the spatial link are considered as the effort variables in fuzzy logic. All of these factors are not similarly relevant to the different places in the district. Bio-physical factors such as soils, water availability, slope and altitude have been the emphasis as the important factors of land suitability classification. Biophysical factors tend to remain stable, unlike socio-economic factors that are affected by social, economic and political settings (Dent and Young, 1981; Trianta, et al, 2001). Land suitability contains the physical atmosphere like; soil pH, climate, relief, soils and hydrology (Tibbitts and Aubel, 1980). Considering the factors which have been earlier studied in different studies in the different portion of India and contrasting them with the scenario of the Uttar Dinajpur District, the present study could finalize ten factors having an appropriate influence on land suitability for paddy, wheat and potato cultivation. Not only that, one suitable indicator for each factor (i.e. ten variables) was used as the input variable for the fuzzy logic models (table 4.8).

Table 4.8 Agricultural land suitability based on land qualities.

Factors (rooting depth 0-20 cm)	**Suitability class and rating scale**				
	S1	**S2**	**S3**	**N1**	**N2**
Altitude (m)	<24	24-48	48-72	72-96	>96
Slope (°)	<2	2-4	4-6	6-8	>8
Drainage	<1	1-2	2-3	3-4	>4
CEC	>29	29-23	23-17	17-11	<11
pH	<5.8	-	5.8-6.3	-	>6.3
Sand (%)	<29.5	29.5-37	37- 44.5	44.5-52	>52
Silt (%)	<28	28-33	33-38	38-43	>43
Clay (%)	<19.5	19.5-25	25-30.5	30.5-36	>36
Water availability (%)	>84	84-78	78-72	72-66	<66
Workability	<1	-	1-2	-	>2

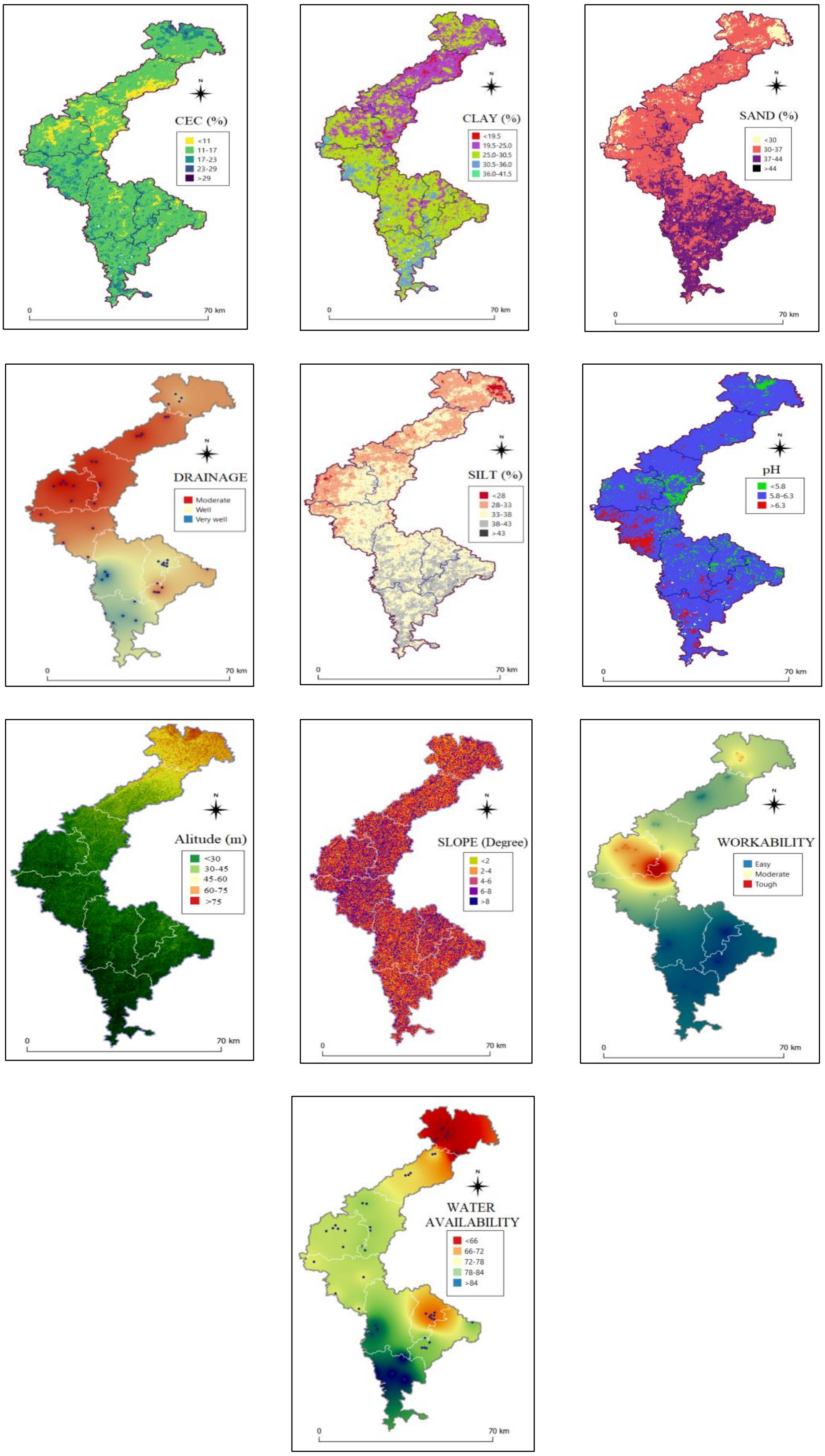
Source: Compiled by the researcher.

There are ten dependent variables which are used as input variables i.e. altitudes, slope, water availability, workability, drainage, CEC, clay, sand, silt and p^H which are explanatory to the determination of suitability classes in the study.

4.1.2.7 Fuzzy classes for the output variable

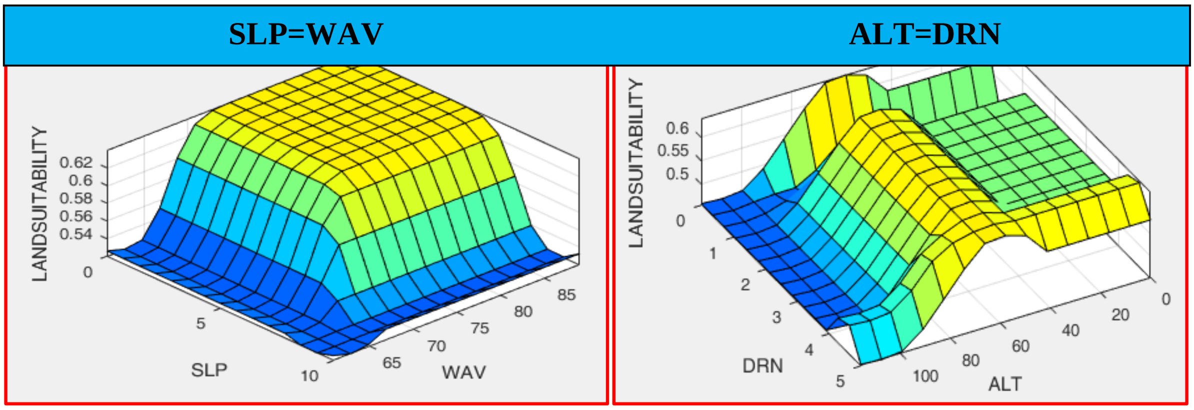
The result of final land suitability classification obtained using fuzzy logic is further disaggregated into five classes, namely ‘very unsuitability’, ‘unsuitability’, ‘average’, ‘suitability’, and ‘very suitability’ for land suitability. The highest score will be very suitable land for agricultural purpose and the lowest scores will be the very unsuitability land for agricultural purposes.

Input layers in fuzzy interface system for generating land suitability map



Source: Prepared by the researcher based on land quality data.

Figure 4.9 Different input layers in fuzzy logic of land suitability of different crops.



Source: Compiled by the researcher.

Figure 4.10 Representation of the result of weight assigned as a different scale to the different variables (paddy).

1) Land suitability for Paddy cultivation

The land suitability of paddy can be used as a point for land use choice-making. A possible classification of land suitability for agriculture is shown in table 4.9. In this study, there has been entire liberty to set the output range in fuzzy model for the proper output and has to be used for better mapping and the fuzzy output was set to the range between 0 to 1.

Table 4.9 The output variable and respective classes of paddy cultivation.

Variables	Very unsuitability	Unsuitability	Average	Suitability	Very suitability	Total
Index of suitability of paddy	<0.20	0.20-0.40	0.40-0.60	0.60-0.80	>0.80	5 Category
Total area (ha)	2,799.60	37,242.80	2,15,549.60	57,626.00	782.00	3,14,000
Percentage (%)	0.89	11.86	68.64	18.35	0.26	100.00

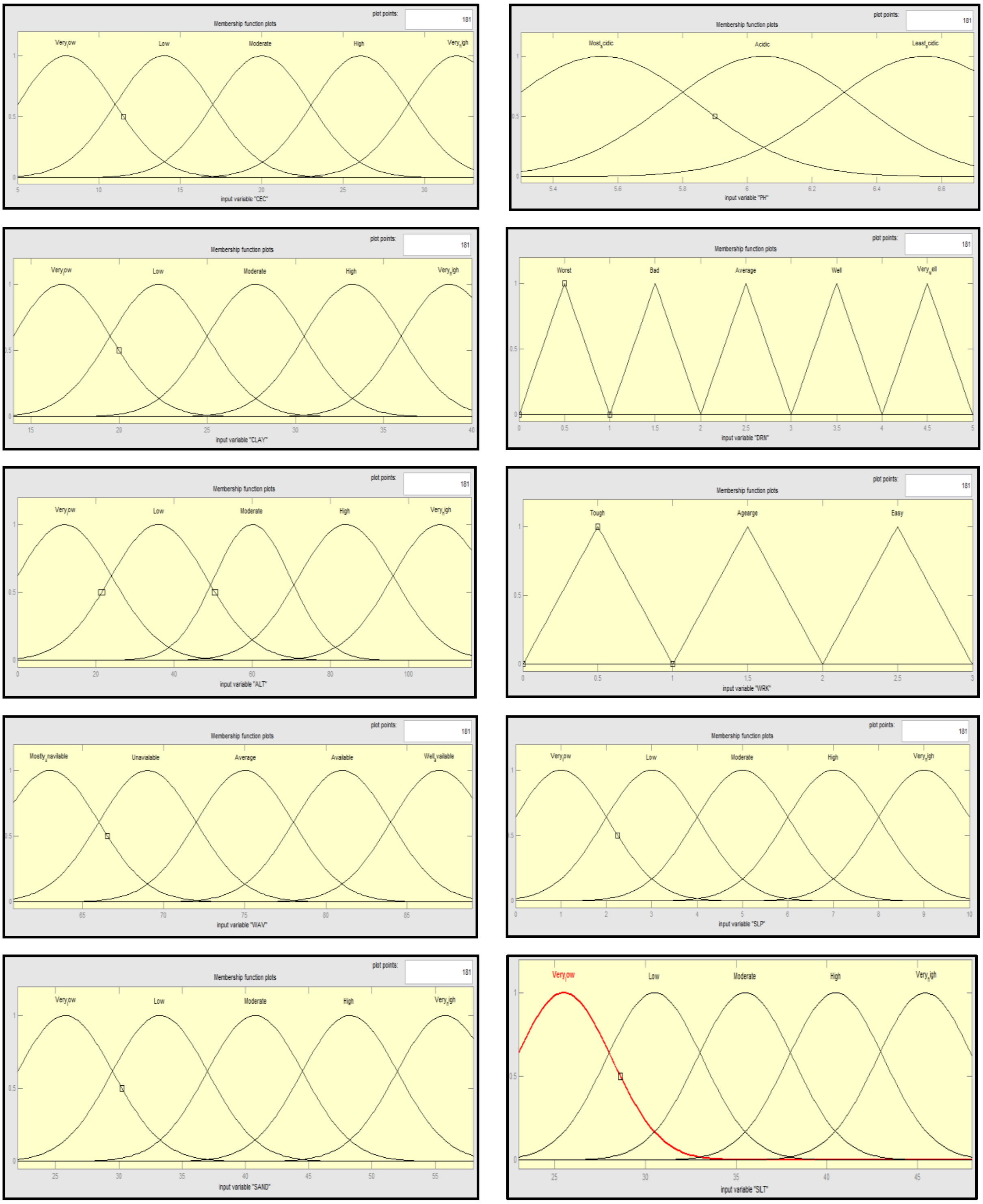
Source: Computed values compiled by the researcher.

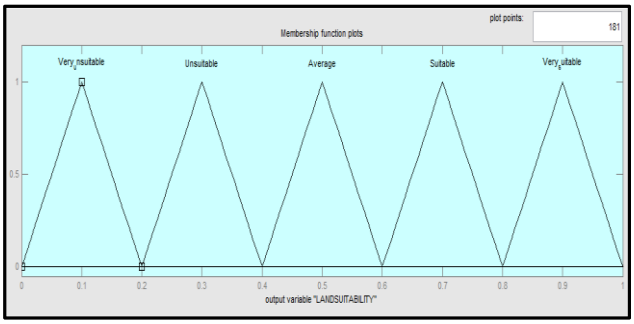
4.1.2.8 Assigning fuzzy membership functions

Fuzzy membership function expresses the degree value of a variable, having the likelihood to influence the result of suitability class. In this study, all the continuous input variables are assigned the ‘gauss’ (i.e. Gaussian) and discrete variables as ‘triangular’ Membership Function (MF) ((i.e. discrete input) in MATLAB’s function editor. In this way, the output variable has been assigned the ‘triangulation’ (i.e. defuzzified output) Membership Function (MF) (figure 4.11). Same initial rules has been used for paddy, wheat and potato crops.

4.1.2.9 Initial rules to link inputs variables with the output results in a fuzzy model

There are significant relations among inputs variables with the output variables for the quality of the outputs result from the fuzzy model.

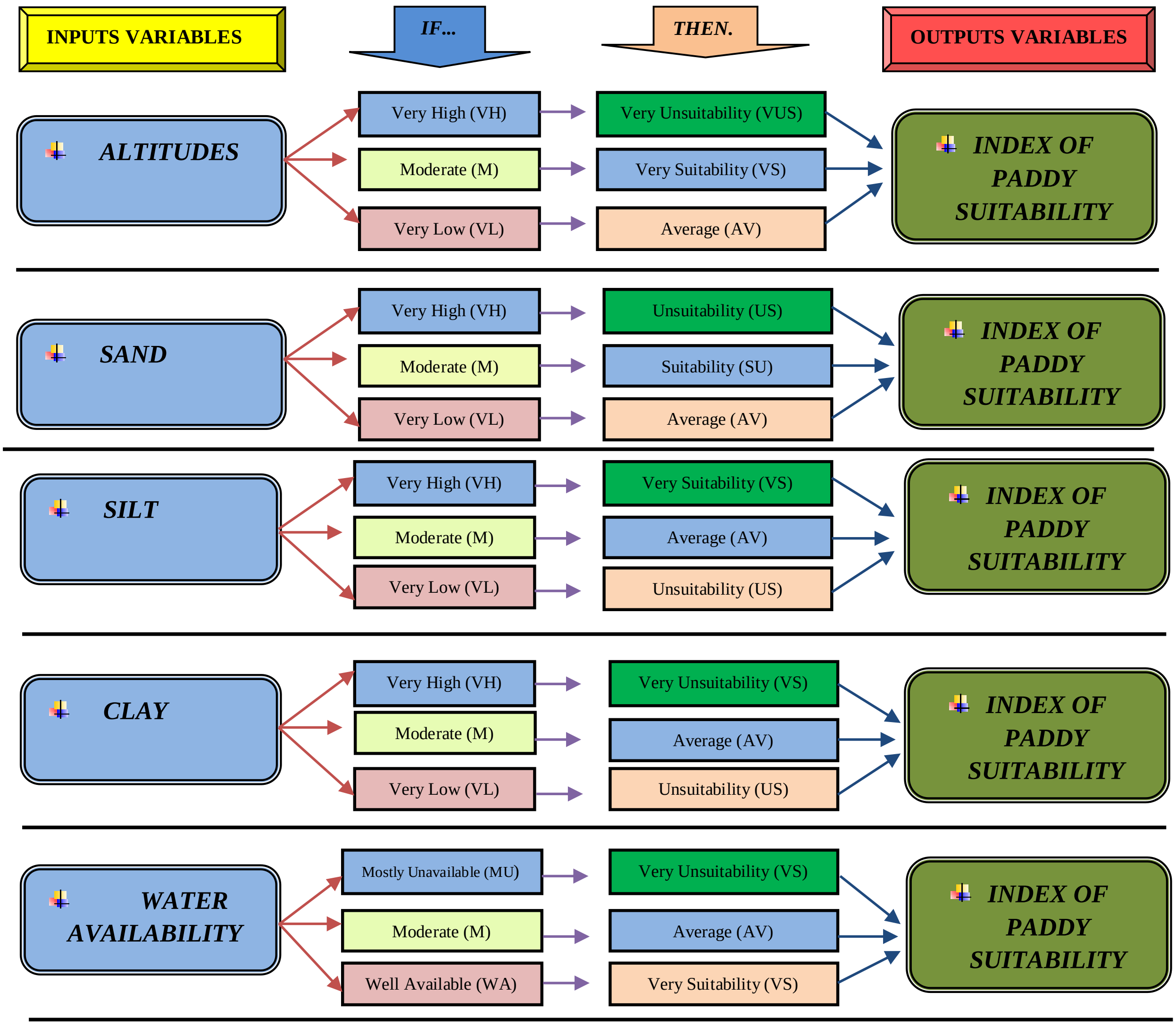




Note: All membership (10 variables +1final land suitability output plot) functions are sereen printing features from MATLAB 17 Software.

Figure 4.11 Membership functions of each factor (all input and output variable).

The fuzzy model depends on effective examination of the actual earth scenario into the model by the establishing associates between the inputs variable to the outputs variable with suitable rational statements. The suitable linking rules used in the study and its results are summarized in figure 4.12.



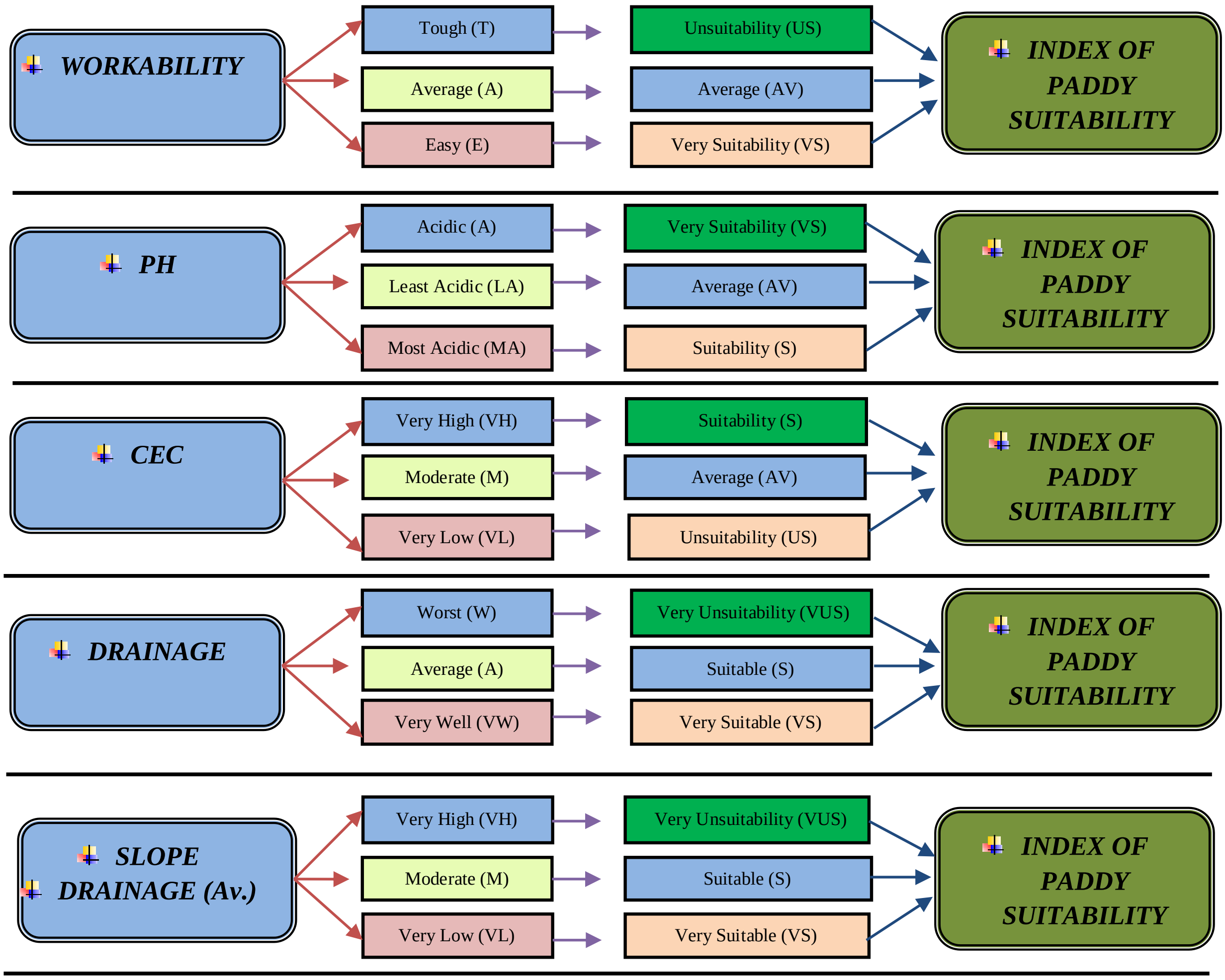


Figure 4.12 Graphical representation of different variables used in the fuzzy editor for connecting inputs variables with output variables results by the researcher.

Analyzing both table 4.9 and figure 4.13, the suitability of agriculture map resultant from multi-criteria evaluation has shown different classes for the degree of suitability which vary from very unsuitability to very suitability with recognized ranges. The whole Uttar Dinajpur District has been divided into five categories of land suitability for paddy cultivation and the major observations are through as under;

i. Very unsuitability zone for paddy cultivation

Very unsuitability class of land suitability for paddy is in the district with a composite score of <0.20. This zone is determinate in the northern part and central part of the district. And another small zone situated in the south-eastern part of the district which accounts for 0.89 per cent of the total land area (table 4.9 & figure 4.13). This area is considered by the high degree of slope, soil p^H is high, presence of high sand and water availability is less than 66 per cent etc. as a result of which they are not suitable for paddy. Not only that, this zone constitutes the wastelands and is most suitable for pastoral activities.

ii. Unsuitability zone for paddy cultivation

Unsuitability class of land use has a composite score of 0.20-0.40 and it confined to 11.86 per cent of the total district (table 4.9). This category of land suitability zones is found mainly in two places, one zone in the northern part, central-eastern part and another zone confined in the southern-eastern part of the district located in between Hemtabad and Kaliaganj Block (figure 4.13). The causes of unsuitability in this zone are presence of modest slope, soil p^H moderately high, altitude comparatively high 72-96 m, slope 6-8^o, groundwater resources are poor to negligible and clay less than 30 per cent, etc.

iii. Average suitability zone for paddy cultivation

The average suitability class of paddy is found mainly in a narrow strip in the north-eastern part of the district. The composite score of this zone is 0.04-0.60 which accounts for 68.64 per cent (2,15,549.60 hectares i.e. the 1st position) of the total area (Uttar Dinajpur District). It is also found in southern and small patches in northern part where all ten factors of average conditions are present.

iv. Suitability zone for paddy cultivation

Suitability class of paddy has a composite score of 0.60-0.80 and is confined to 18.35 per cent of agricultural land of the total district (table 4.9). This category of land is located in the central part of the district (figure 4.13) where availability of irrigation supply, sand and silt conditions are good, plain land area is there and lands are fertile.

v. Very suitability zone for paddy cultivation

The total area covered of the very suitability class of paddy is 782 hectares (table 4.9) i.e. 11.25 per cent (figure 4.13) of the total study area. The composite score of the very suitability zone is >0.80 and located in southern part of the district. The conditions of all contributing factors are best for paddy cultivation.

2) Land suitability for Wheat cultivation

The land suitability of wheat can be used as a point for agricultural land use choice-making. A possible classification of land suitability for wheat is shown in table 4.10. In this study, there has been entire liberty to set the output range in fuzzy model for the proper output and has to be used for better mapping and the fuzzy output was set to the range between 0 to 1.

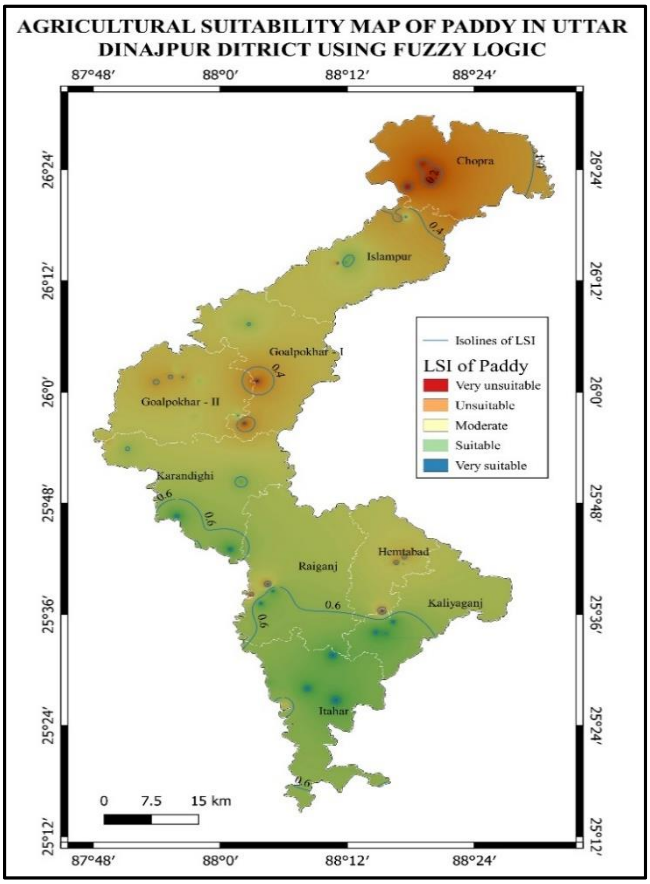


Figure 4.13 Paddy suitability map of Uttar Dinajpur District.

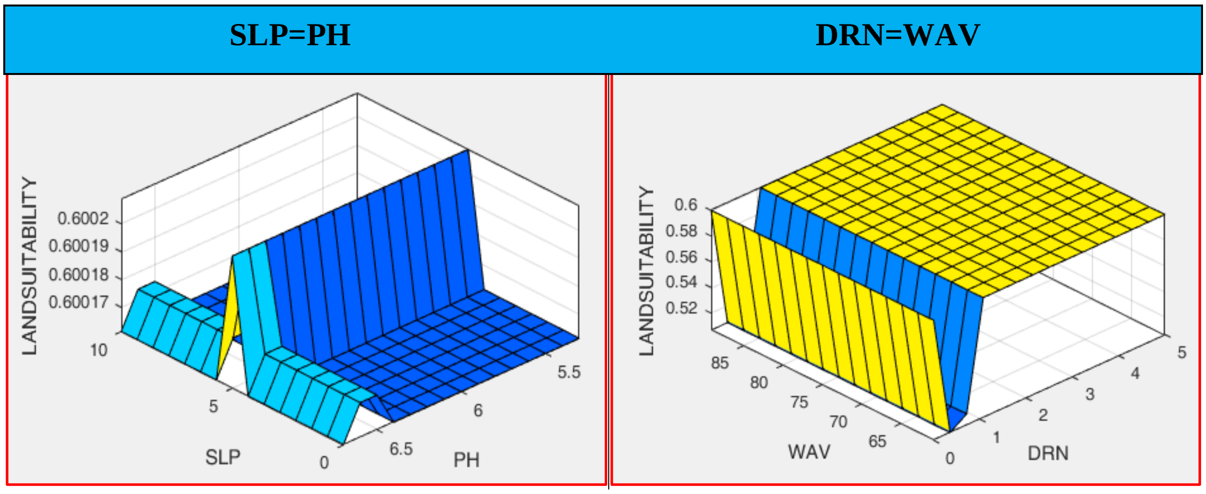


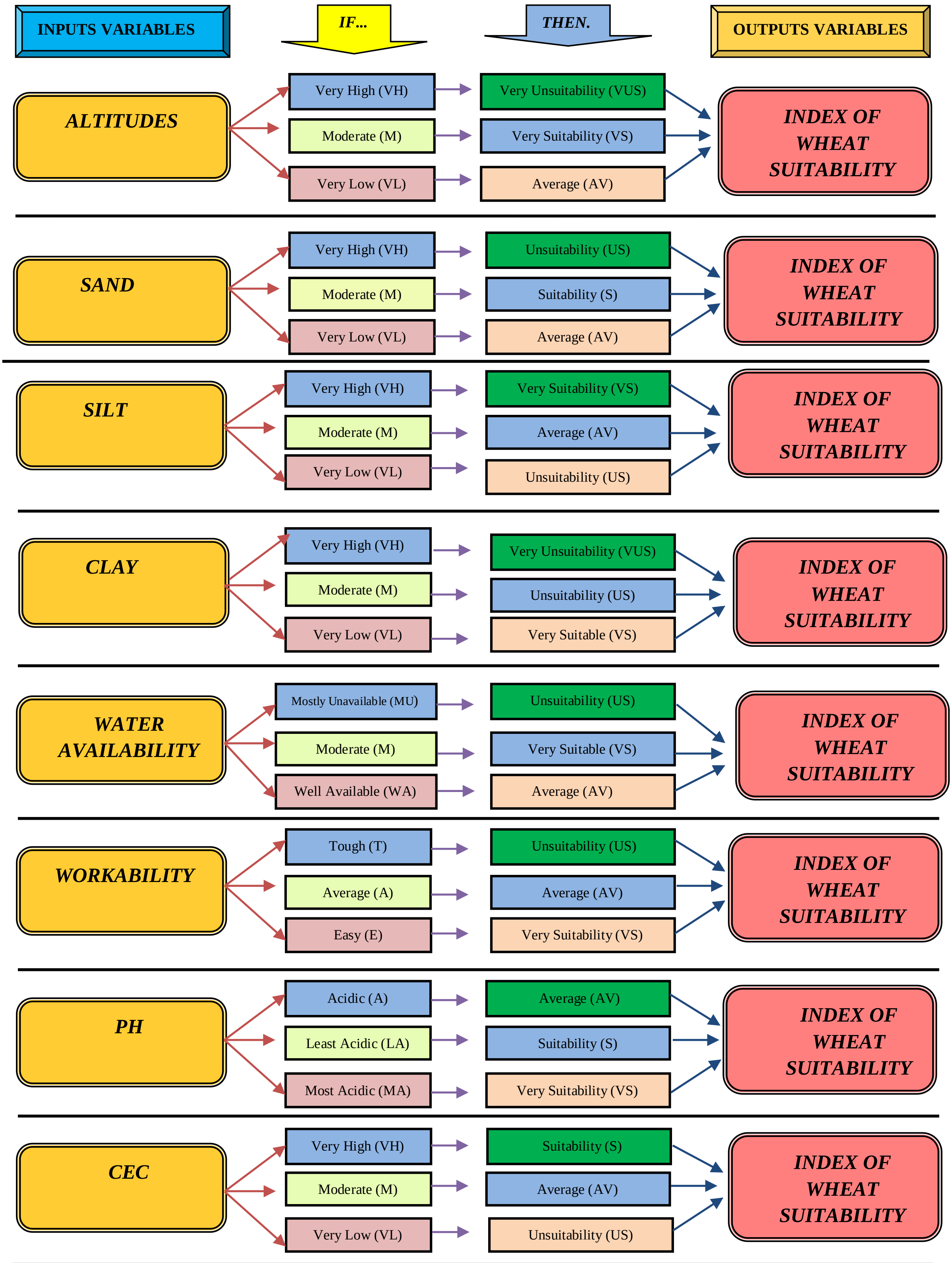
Figure 4.14 Representation of the result of weight assigned as a different scale to the different variables (wheat).

Table 4.10 The output variable and respective classes of wheat cultivation.

Variables	Very unsuitability	Unsuitability	Average	Suitability	Very suitability	Total
Index of suitability for wheat	<0.20	0.20-0.40	0.40-0.60	0.60-0.80	>0.80	5 Category

Total area (ha)	255.20	1,30,013.6	1,63,214	19,602.8	914.4	3,14,000.00
Percentage (%)	0.08	41.40	51.97	6.24	0.29	100.00

Source: Computed values compiled by the researcher.



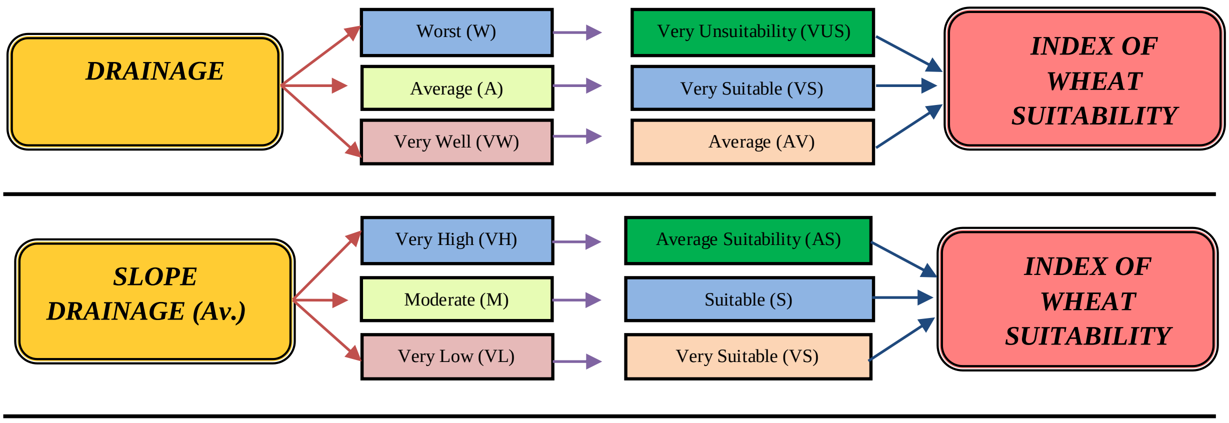


Figure 4.15 Graphical representation of different variables used in the fuzzy editor for connecting inputs variables with output variables results by the researcher.

i. Very unsuitability zone for wheat cultivation

Very unsuitability class for wheat cultivation in the district with a composite score of <0.20. This zone is located in the south-western part of the district. And another small zone situated in the southern part of the district which accounts for 0.08 per cent of the total land area (table 4.10 & figure 4.16). This area is considered by the high degree of slope, soil p^H is high and presence of high sand etc. as a result of which they are not suitable for wheat cultivation.

ii. Unsuitability zone for wheat cultivation

Unsuitability class of wheat has a composite score of 0.20-0.40 and it confined to 41.40 per cent of the total district (table 4.10). This wheat zones is found mainly in two places, one zone in the south-eastern part and another zone is confined in the northern part of the district (located in between Kaliaganj and Itahar Block (figure 4.16). The causes of unsuitability in this zone are presence of modest slope, soil p^H moderately high, irrigation condition are poor to negligible and clay type soil, etc.

iii. Average suitability zone for wheat cultivation

The average suitability class of wheat cultivation is found mainly in a narrow strip in the north-eastern part of the district. The composite score of this zone is 0.04-0.60 which accounts for 51.97 per cent of the total study area. It is also found in Chopra, Goalpokher-I and Kaliaganj Block where all ten factors of average conditions are present.

iv. Suitability zone for wheat cultivation

Suitability class of wheat ciltivation has a composite score of 0.60-0.80 and is confined to 6.24 per cent of agricultural land of the total district (table 4.10). This category of land is located in the north-central part of the district (figure 4.16) due to availability of irrigation supply, situation of NPK medium to high, plain land etc.

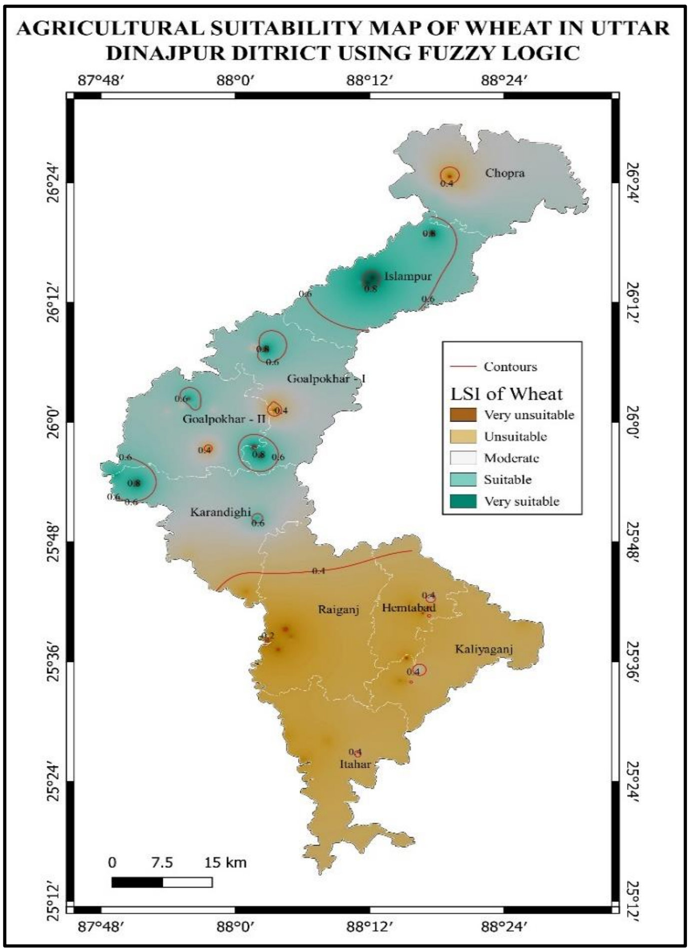


Figure 4.16 Wheat suitability map of Uttar Dinajpur District.

v. Very suitability zone for wheat cultivation

The total area covered of the very suitability class of wheat is 914.4 hectares (table 4.10) i.e. 0.29 per cent (figure 4.16) of the total study area. The composite score of the very suitability zone is >0.80 and it is located in Islampur, Goalpokher-II and Karandighi Block of the district. The conditions of all contributing factors are best for wheat cultivation.

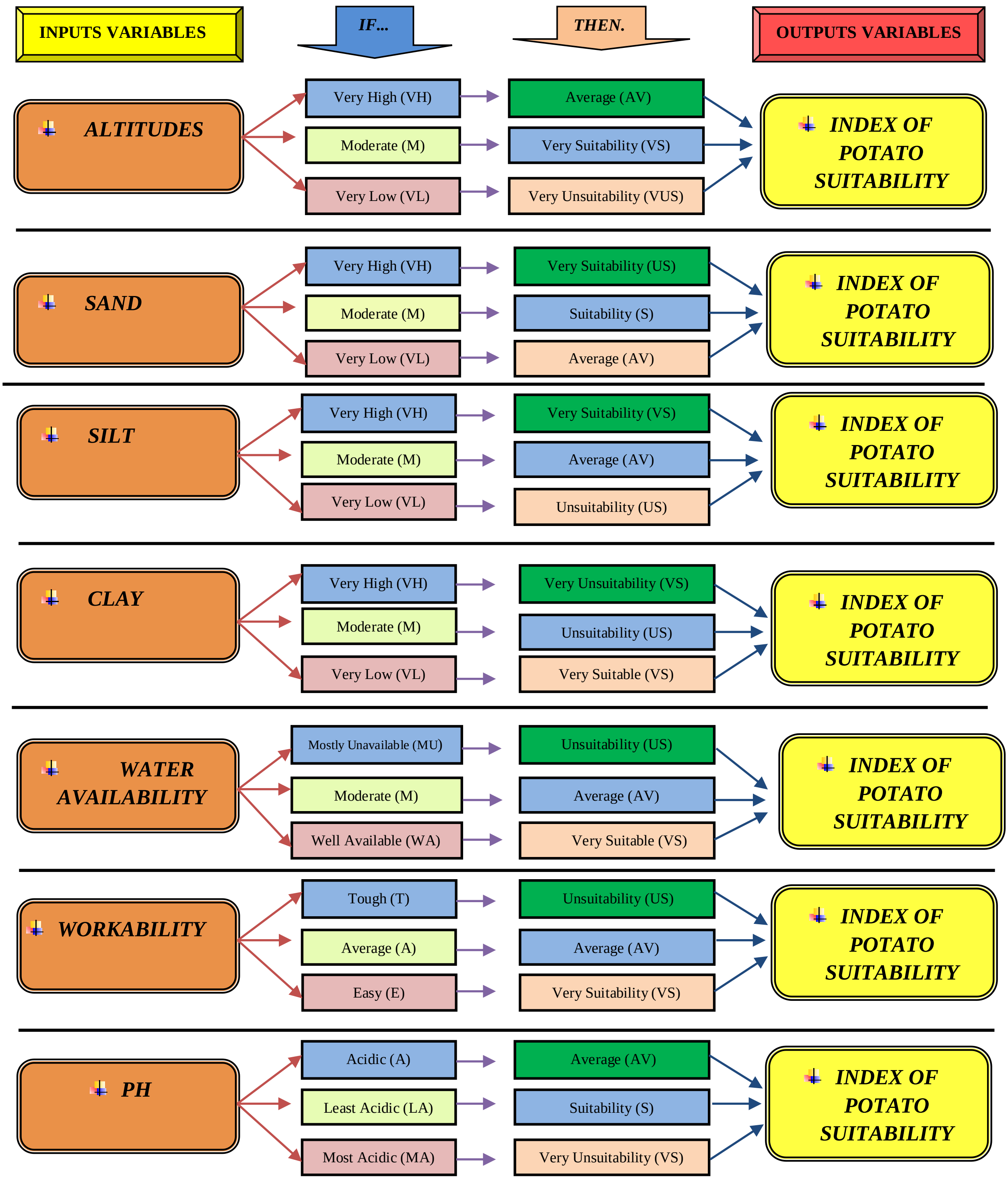
3) Land suitability for Potato cultivation

The land suitability of potato cultivation can be used as a point for agricultural land use choice-making. A possible classification of land suitability for potato is shown in table 4.11. In this study, there has been entire liberty to set the output range in fuzzy model for the proper output and has to be used for better mapping and the fuzzy output was set to the range between 0 to 1.

Table 4.11 The output variable and respective classes of potato cultivation.

Variables	Very unsuitability	Unsuitability	Average	Suitability	Very suitability	Total
Index of the suitability for potato	<0.20	0.20-0.40	0.40-0.60	0.60-0.80	>0.80	5 Category
Total area (ha)	25,338.40	1,04,398.00	86,993.20	65,291.20	31,979.20	3,14,000.00
Percentage (%)	8.06	33.24	27.70	20.79	10.18	100.00

Source: Computed values compiled by the researcher.



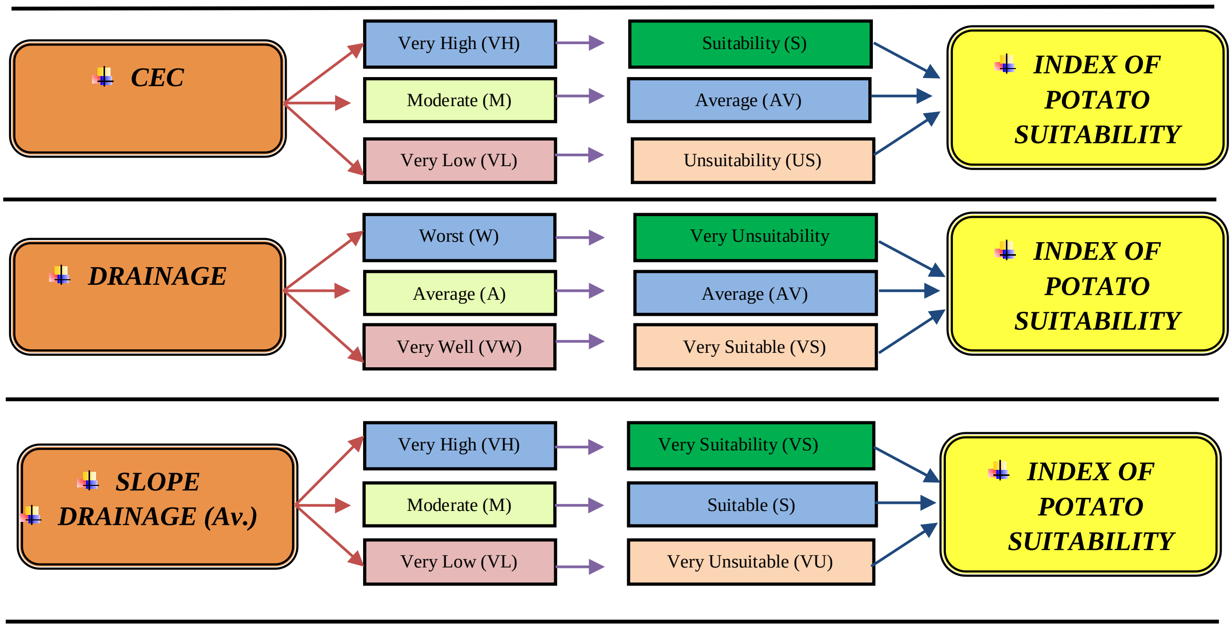


Figure 4.17 Graphical representation of different variables used in the fuzzy editor for connecting inputs variables with output variables results by the researcher.

i. Very unsuitability zone for potato cultivation

Very unsuitability land for potato is in the district with a composite score of <0.20. This zone is located in the south-eastern and south-western part of the district which accounts for 8.06 (25,338.40 hectares) per cent of the total land area (table 4.11 & figure 4.18). This area is considered by the medium degree of slope, soil p^H is high, presence of high sand in soil etc. as a result of which they are not suitable for potato cultivation.

ii. Unsuitability zone for potato cultivation

Potato unsuitability class has a composite score of 0.20-0.40 and it confined to 33.24 per cent (1,04,398.00 hectares) of the total district (table 4.11). This potato zones is found mainly in southern and central part and another small zone confined in the northern part of the district located in between Chopra and Islampur Block (figure 4.18). The causes of unsuitability in this zone are presence of modest slope, soil p^H moderately high and irrigation facility are poor to negligible etc.

iii. Average suitability zone for potato cultivation

The average suitability class of potato is found mainly in three blocks namely Goalpokher-II, Hemtabad and Itahar of the district. The composite score of this zone is 0.04-0.60 which accounts for 27.70 per cent (86,993.20 hectares) of the total area (Uttar Dinajpur District). In three blocks all ten factors of average conditions are present for potato suitable.

iv. Suitability zone for potato cultivation

Suitability class of potato land use has a composite score of 0.60-0.80 and is confined to 20.79 per cent of agricultural land of the total district (table 4.11). This category of land is located in the north-central part (Chopra, Goalpokher-I & II and Hemtabad) of the district (figure 4.18) where availability of irrigation supply, suitable sand and silt conditions, plain land and fertile land are also there. So, as a vegetable crop, potato cultivation is spreading in vast area.

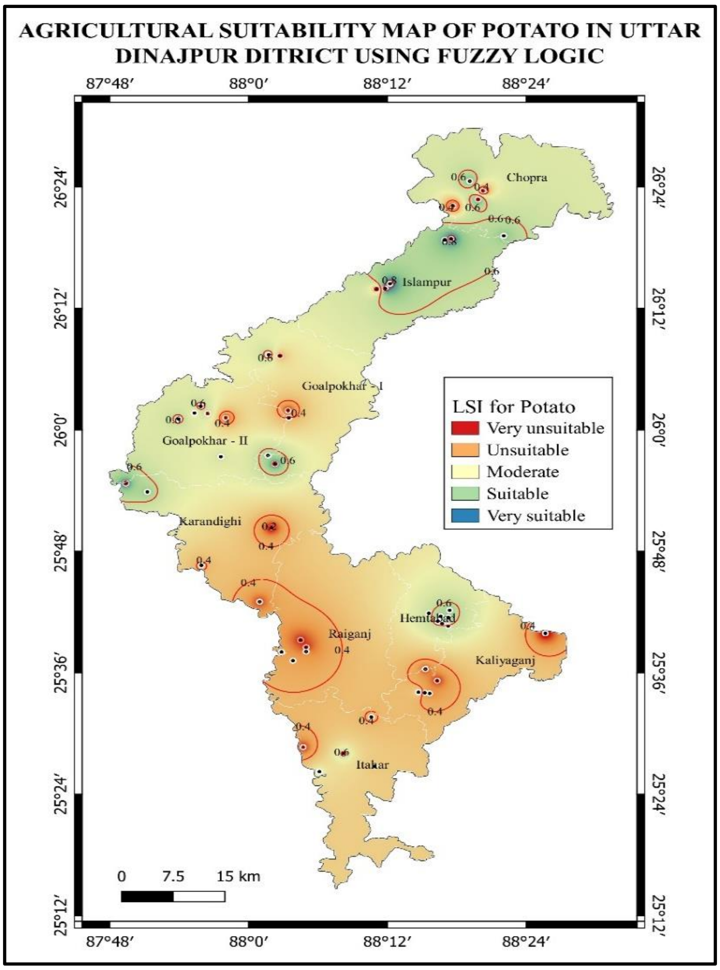


Figure 4.18 Potato suitability map of Uttar Dinajpur District.

v. Very suitability zone for potato cultivation

The total area covered of the very suitability class of potato is 31,979.20 hectares (table 4.11) i.e. 10.18 per cent (figure 4.18) of the total study area. The composite score of the very suitability potato zone is >0.80 and located in Islampur, Goalpokher-II, south-eastern part of Hemtabad block, whole portion of Islampur Block of the district. The conditions of all contributing factors are best for potato cultivation.

4.2 Conclusion

Now-a-days, the study exposed the importance of agriculture land suitability studies for taking up the appropriate crop which gives higher productivity. The application of the agricultural land capability and suitability fuzzy indicator technique is a hopeful way to carry out these responsibilities. It provides a chance for evaluation of the land capability and suitability of agricultural lands as a degree or grade of presentation while the lands are used for agricultural objectives. In this way, with the help of multifactor analysis, the final output land capability and suitability map for agricultural crops can be developed. Although, it is not possible to properly develop data of all region due to the lack of the data set. Hence, the present need of the district is to better carry out the agricultural and related activities with proper understanding of the level of capability and suitability and then proper management. This study clearly explains the methodology of land capability and suitability classification for agricultural land and the actual area and percentage distribution of each land category. Likewise low capability class is represented as 15.31 per cent of the district and medium capability class is represented in the area as 72.26 per cent. But the last category (high capability class) is represented the area as 12.43 per cent of the district. On the other hand, land suitability situation in very unsuitability class is represented in the area of 10.17 per cent and unsuitability of 30.77 per cent with different limitations. But average to very suitability for the agricultural area is about 59 per cent of the total area. In these zones (average, suitability and very suitability) all the indicators are best condition as well as for land use. On the basis of the study, it is observed that about 59.40 per cent area is suitable for cultivation but present land use study discloses that about 72.11 per cent area is acquiescent to cultivation. This gap indicates the wrong use of land and a very narrow scope for further expansion of area under cultivation.

It is amazing that, in the statistical methods, the use of fuzzy logic set theory to define the soil survey data can play an important role to describe and generate the required numerical parameters. Not only that, the result of the fuzzy logic method is very important for further development of land use study. Specially, which portion of land suitable for what types of crops. As discussed earlier, in the study area total favourable factors as suitable for agriculture capability condition is between medium to high and suitability condition is average to very suitable land and covers maximum area in the district i.e. indicates the agricultural production have good prospects.

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