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Land Suitability Assessment for Crop Cultivation by Using Remote Sensing and GIS

Jadab Chandra Halder[1]

[1] Department of Geography, University of Calcutta, Kolkata, India

Correspondence: Jadab Chandra Halder, Department of Geography, University of Calcutta, 35 B C Road, Kolkata-700019, India. Tel: 91-9088-232-620. E-mail: hcjadab@yahoo.com

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Abstract

Land evaluation is the process of assessing the possible uses of land for different purposes. Land suitability analysis is a method of land evaluation, which measures the degree of appropriateness of land for a certain use. The present study is a qualitative evaluation of land to determine land suitability in Ghatal block, Paschim Medinipur district, West Bengal for rice and wheat cultivation based on four pedological variables, like Nitrogen-Phosphorus-Potassium (NPK) status, soil reaction (pH), Organic Carbon (OC) and soil texture that are mandatory input factors for crop cultivation. All these factors have been rated based upon the proposed method of Sys et al. (1993). The qualitative approach given by FAO (1976) has also been used to classify the land on the basis of their suitability ranked classes (e.g. S1, S2, S3, N1 and N2). This study proposes an integrated methodology for analyzing and mapping of land suitability using the Remote Sensing and GIS techniques. The result indicated that only 12.71% of agricultural land can be demarcated as highly suitable for rice cultivation whereas 7.78% of agricultural land as highly suitable for wheat cultivation in the study area.

Keywords: FAO (1976), land evaluation, land suitability, NPK status, Remote Sensing and GIS

1. Introduction

Land suitability is the ability of a portion of land to tolerate the production of crops in a sustainable manner. The analysis allows identifying the main limiting factors of a particular crop production and enables decision makers to develop a crop management system for increasing the land productivity. The FAO defined that ‘The suitability is a function of crop requirements and land characteristics and it is a measure of how will the qualities of land unit matches the requirements of a particular form of land use’ (FAO, 1976). Crop land suitability analysis is a prerequisite to achieve optimum utilization of available land resource for agricultural production in a sustainable manner. In Ghatal block, rice and wheat are two main food crops, but their yields are far below their agronomic and genetic potential. Hence this study has been envisaged with a view to determine the pedological land suitability for both crops using a Remote Sensing and GIS approach. The aim of this approach is to provide more flexible and superior mechanism to the decision makers in order to evaluate the effective factors. This research work provides information at local level which could be utilized by farmers for selecting the proper cropping pattern to overcome the major pedological constraints.

2. Study Area

Covering of an area about 236.77 sq. km, Ghatal block extending from 21°39'00" to 21°47'19" N and 87°35'25" to 87°47'09" E of Paschim Medinipur District, West Bengal, India is defined as study area. The area is bordered by Howrah District in the north, Daspur-II block of Paschim Medinipur District in the east, Daspur-I block of Paschim Medinipur District in the south and Chandrakona-I block of Paschim Medinipur District in the west (Figure 1). The study area is intersected by Silai, Rupnarayan and Sankari Rivers and Tarayoti canal. The area experiences a tropical monsoon climate and receives mean annual rainfall ranging from 788.20 mm (2001) to 1572.90 mm (1995) which is mostly received during south west monsoon period followed by the post monsoon period from October to November. Unfortunately the rainfall in winter is considered as insufficient for growing of different Rabi crops.

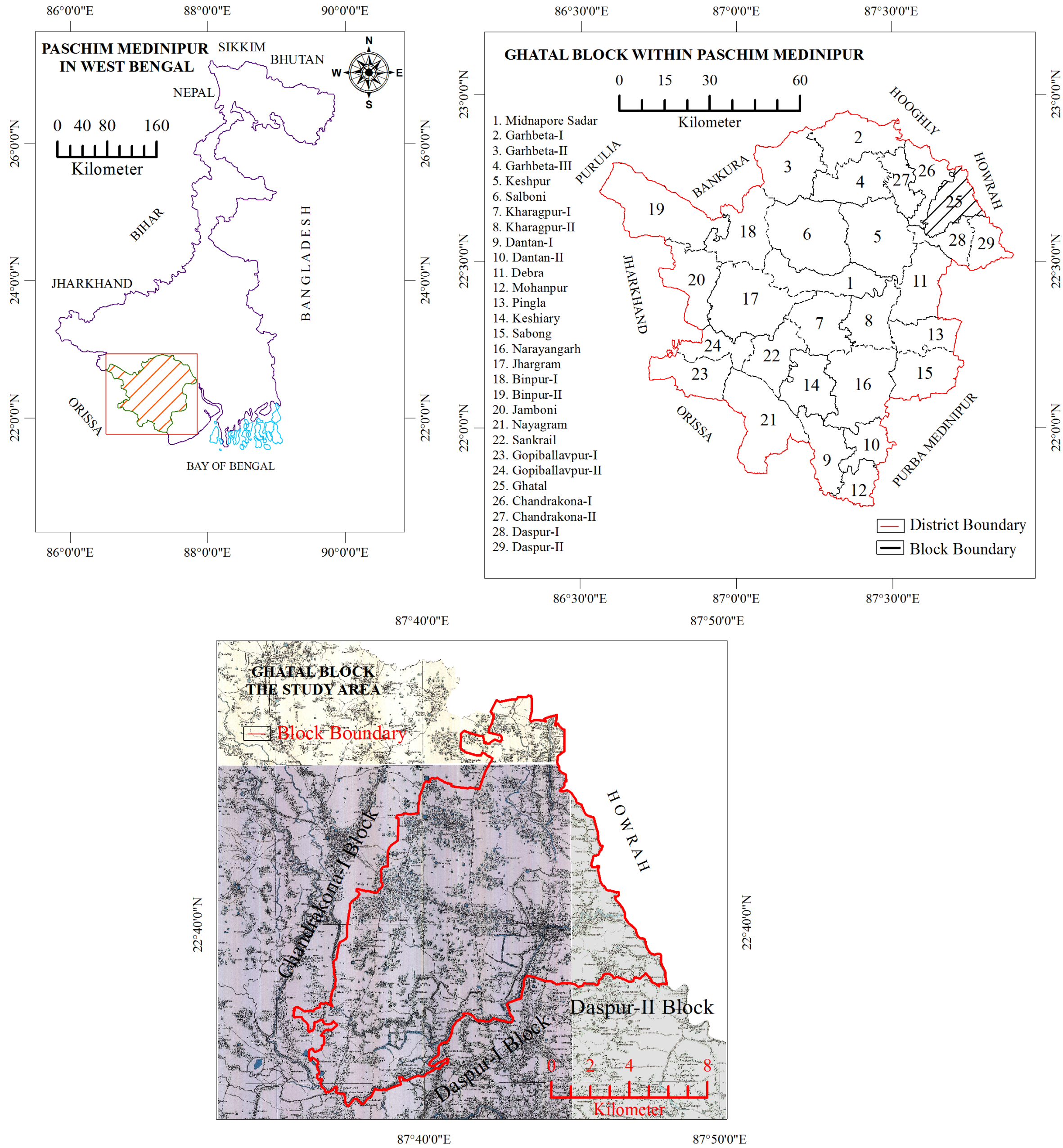

Figure 1. Location map of the study area

3. Objective

The major objectives of the present study are:

A] To develop a GIS based approach for land suitability assessment of two food crops namely rice and wheat, which will assist land managers and land use planners to identify the areas with pedological constraints for rice and wheat cultivation.

B] Specially this suitability analysis has developed for farmers and other authorities who are engaged with agricultural development.

4. Data Source

In this present study, different types of data have been used for land suitability analysis of rice and wheat cultivation. The Survey of India Toposheets (No. 73N/9, 73N/10 and 73N/14) and IRS P6 LISS-III, 2010 satellite data have been used for extracting study area and agricultural land. Besides these, the raster data set contains the spatial variations of properties including the availability of different nutrients have been taken from National Bureau of Soil Science & Land Use Planning (NBSS & LUP), Kolkata. Details of the data sources are given in Table 1.

Table 1. Different data used for land suitability analysis

Data/Maps	Year	Source
Soil data and maps	2010	NBSS & LUP, Kolkata
Topographical maps	1971	Survey of India
IRS P6 LISS-III Image	2010	University of Calcutta

5. Methodology

To fulfill the aforesaid objectives, Remote Sensing and GIS techniques have been used. The methodology followed in present study can be classified into three steps (Figure 2). In this paper the classification scheme of land suitability and their rating values have been adopted from proposed classification system of FAO and Sys et al. (Tables 2 and 3).

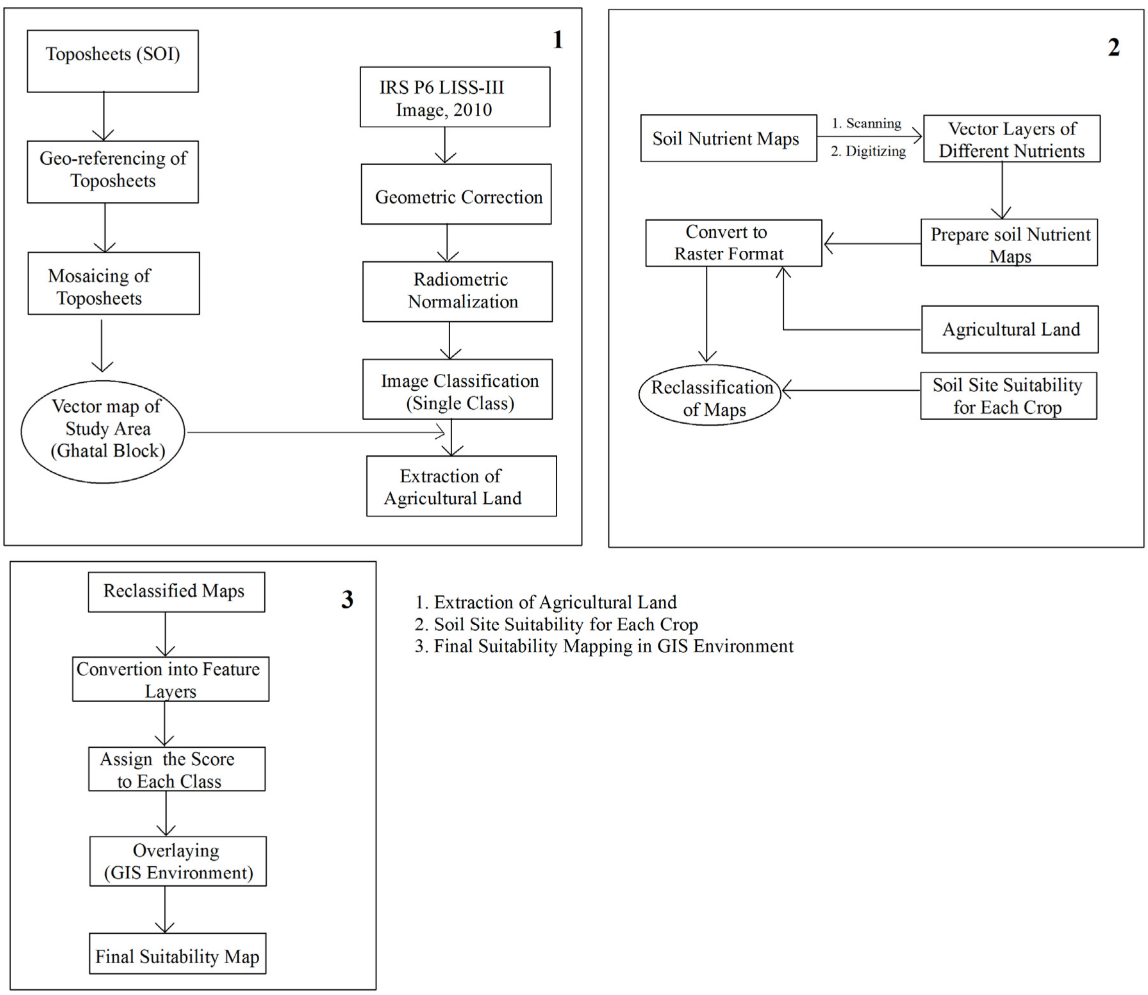

Figure 2. Flowchart of the methodology followed in the study

5.1 Extraction of Study Area and Agricultural Land

The study area has been extracted from mosaiced toposheet through onscreen digitization of the block boundary in GIS environment. In mean time the agricultural land has been delineated by supervised image classification and has been extracted by using the block boundary as Area of Interest (AOI) tool.

Table 2. Structure of the suitability classification

Order	Class	Description
S	S1	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity and benefits and will not raise inputs above an acceptable level.
	S2	Land having limitations which in aggregate are moderately severe for sustained application of a given use, the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use.
	S3	Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity and benefits, or increase required inputs, that this expenditure will be only marginally justified.
N	N1	Land having limitations which may be surmountable in time but which can not be corrected with existing knowledge at currently acceptable cost, the limitations are so severe as to preclude successful sustained use of the land in the given manner.
	N2	Land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land in the given manner.

Source: FAO Soils Bulletin 32, 1976.

Table 3. The soil requirements of rice and wheat

Soil Characteristics	**Class, Degree of Limitation and Rating Scale**					
FAO Framework	S1		S2	S3	N1	N2
Restriction Levels of Sys et al.	0	1	2	3	4	
Parametric Evaluation of Restrictions	100-95	95-85	85-60	60-40	40-25	25-0
Crop: Rice						
Surface Texture	Cm, SiCm, C+60v, C+60s	C-60v, C-60s, SiCs	Co, SiCl, Cl, Si	SiL, SC	-	L and Lighter
pH	6.5-6.0	6.0-5.5	5.5-5.0	5.0-4.5	-	<4.5
Organic Carbon (%)	>2.0	2.0-1.5	1.5-0.8	<0.8	-	-
NPK Status	HHH	MMM	MML	LLL	-	-
Crop: Wheat						
Surface Texture	SiC, Co, Si, SiL, Sicl	SC, C>60s, L	C>60v, SCL	SL, LfS	-	Cm, SiCm, LcS,Fs, cS
pH	7.0-6.5	6.5-6.0	6.0-5.6	5.6-5.2	<5.2	-
	7.0-7.5	7.5-8.2	8.2-8.3	8.3-8.5	-	>8.5
Organic Carbon (%)	>1.5	1.5-1.0	1.0-0.5	<0.5	-	-
NPK Status	HHH	MMM	MLL	LLL	-	-

Source: FAO, 1976 and Sys et al, 1993.

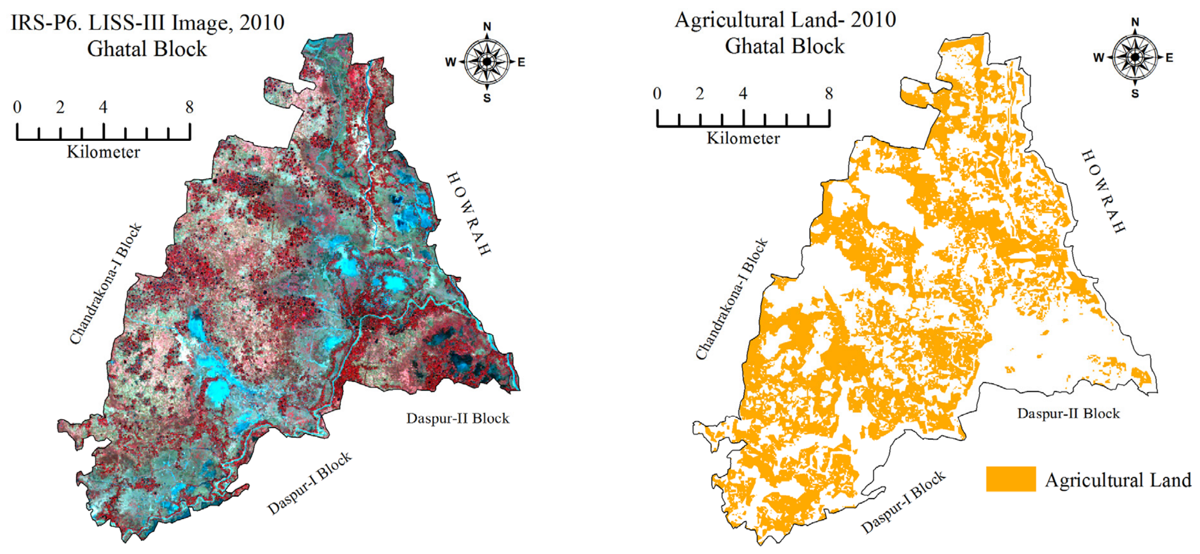

Figure 3. Extraction of agricultural land from IRS P6 LISS-III image

5.2 Soil Site Suitability for Each Crop

In this study, four variables namely, NPK status, soil reaction (pH), Organic Carbon (OC) and soil texture have been considered as specific crop requirement factors to identify the land suitability according to the FAO guidelines (1976). All the paper maps have been scanned and digitized. Feature layers were digitized and attribute data were added for of all these variables using Arc GIS 9.3. These layers were converted into grid format and reclassification was adopted to determine the soil site suitability categories of rice and wheat.

5.3 Suitability Mapping in GIS Environment

In this step the reclassified map (raster format) of each variable has been converted into vector format and has been assigned by the score of each class according to their rating values. Then the vector layers have combined by performing the overlay operation into GIS environment. Finally the suitability maps have been prepared according to the chosen criteria with five suitability categories namely; S1, S2, S3, N1 and N2.

6. Result and Discussion

6.1 Spatial Variations of Soil Properties

The spatial distribution of soils according to the availability of four variables namely NPK status, pH, Organic Carbon (OC) and texture are discussed here under.

6.1.1 Spatial Variation of NPK Status

Within the all nutrients, which are needed for plant growth in large amounts, the primary nutrients are Nitrogen (N), Phosphorus (P) and Potassium (K). The balanced ratio of these three important nutrients (NPK ratio) is an important parameter for crop production. It leads to build up soil health and increase in the crop yields by improving physical, chemical and biological environment of soil. In contrast, the unbalanced NPK ratio leads to soil mining and its sickness. Unbalanced NPK ratio, not only produces low and poor quality yields, but can also leads to mining of soil nutrient reserves which results in short supply (Mahajan & Gupta, 2009). Thus a certain balance among these three nutrients is very essential. The analysis of NPK status of the study area depicted that, the soils of the study area could be categorized into twenty seven groups of the NPK ratio among which 2.78% of soils have high availability of Nitrogen, Phosphorus and Potassium that is corresponding to the ratio HHH, where as 10.05%, and 2.19% of the total soils are falling under MMM and LLL ratio groups. The detailed spatial variations of different ratio groups of NPK ratio are presented in Table 4 and Figure 4 respectively.

Table 4. Spatial variation of NPK status

NPK Status	Area (Km^2)	Area (%)
High-High-Low	1.32	1.14
High-High-Medium	0.15	0.13
High-Low-High	0.05	0.04
High-High-High	3.22	2.78
High-Low-Low	0.12	0.10
High-Low-Medium	1.17	1.01
High-Medium-High	2.14	1.84
High-Medium-Low	4.06	3.50
High-Medium-Medium	2.78	2.39
Low-High-High	1.47	1.27
Low-High-Low	15.12	13.03
Low-High-Medium	9.02	7.78
Low-Medium-High	3.46	2.98
Low-Low-High	0.22	0.19
Low-Low-Low	2.54	2.19
Low-Low-Medium	0.16	0.14
Low-Medium-Low	13.08	11.28
Low-Medium-Medium	5.05	4.35
Medium-High-High	0.54	0.47
Medium-High-Low	8.78	7.57
Medium-High-Medium	3.91	3.37
Medium-Low-High	2.38	2.05
Medium-Low-Low	1.62	1.40
Medium-Low-Medium	2.63	2.27
Medium-Medium-High	4.87	4.20
Medium-Medium-Low	14.48	12.48
Medium-Medium-Medium	11.66	10.05
Block Total	**116.00**	**100.00**

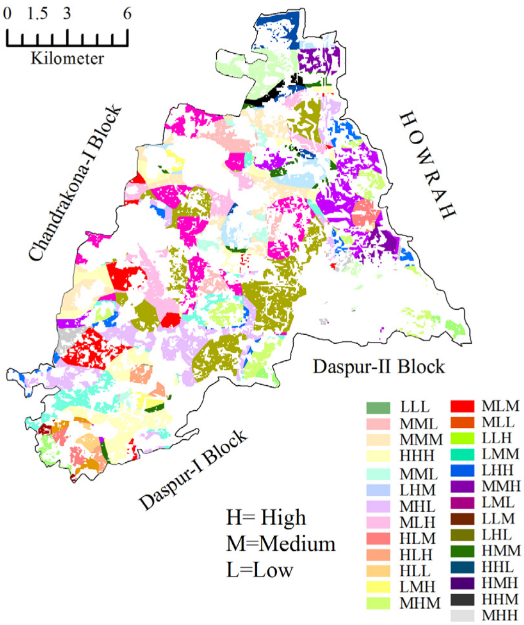

Figure 4. Spatial variation of NPK Status

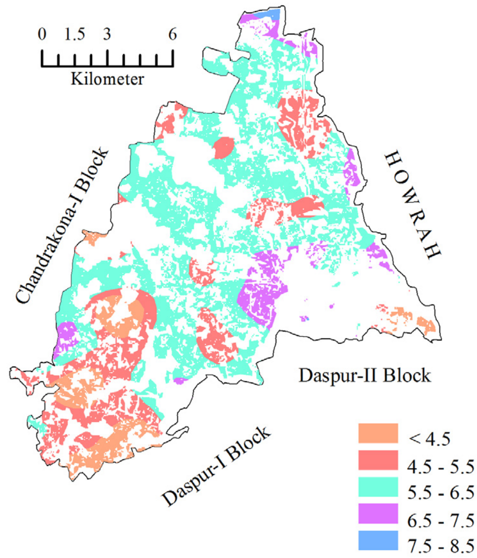

Figure 5. Spatial variation of available pH

6.1.2 Spatial Variation of pH

Soil reaction or pH is an important factor in soil productivity and plant growth. It provides the information about the solubility and thus potential availability or phyto-toxity of elements for crops and subsequently specifies the soil suitability for specific crop (Mustafa et al., 2011). A pH value of 7 means that the soil is chemically neutral, lower values from neutral indicate that the soil is acidic and the higher values indicate the alkalinity of soil. The soil pH of the study area is ranged from 4.2 to 8.76 and for the purpose of suitability analysis; the distribution of pH has been reclassified into five classes. The spatial reclassified variations show that about 66.34 % of the total agricultural lands are demarcated by pH range 5.5 to 6.5. The Table 5 and Figure 5 represent the spatial variations and rating values of pH throughout agricultural lands.

Table 5. Spatial variation of pH

Range of pH	Area (Km^2)	Area (%)
<4.5	10.06	8.67
4.5-5.5	25.71	22.16
5.5-6.5	66.34	57.19
6.5-7.5	13.06	11.26
7.5-8.5	0.83	0.72
Block Total	**116**	**100**

6.1.3 Spatial Variation of Organic Carbon (OC)

Soil OC indicates the organic matter content in the soil which often creates the basis for the successful use of mineral fertilizers. The combination of organic matter and mineral fertilizers provides the suitable environmental conditions for crop as the organic matter improves soil properties and mineral fertilizer supply the plant is needed (FAO, 2000). However OC alone is not sufficient for the satisfactory level of production the farmer is aiming at. Mineral fertilizers have also to be applied in addition. The spatial distributions of OC (Table 6 and Figure 6) show that 10.91 % of the total agricultural land is characterized by high availability of OC (>0.75%), where as 34.10% area by medium availability (0.5-0.75%) and 54.99% area by low availability.

Table 6. Spatial variation of Organic Carbon (OC)

OC in %	Area (Km^2)	Area (%)
<0.5	63.79	54.99
0.5-7.5	39.56	34.1
>7.5	12.65	10.91
Block Total	**116**	**100**

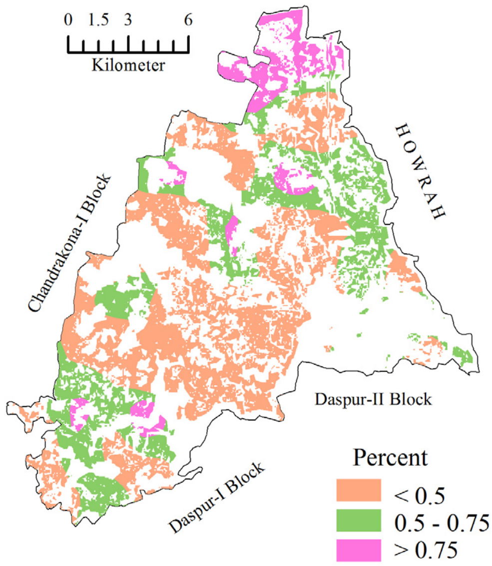

Figure 6. Spatial variation of available Organic Carbon (OC)

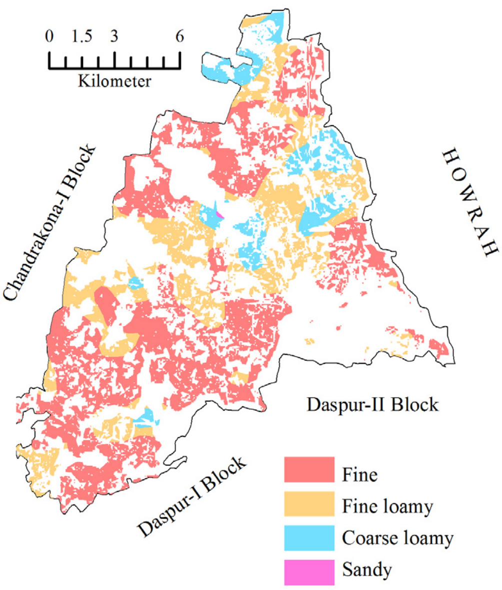

Figure 7. Spatial variation of surface texture

6.1.4 Spatial Variation of Soil Texture

Texture is one of the important parameter of soil. Most of the physical properties of the soil depend upon textural class. Four textural classes have been identified in the study area namely, fine (Sc, Sic, c), fine loamy (Scl, cl, Sicl), coarse loam (sl, l, sil) and sandy (Ls). The spatial variations of soil textural classes are presented in Table 7 and Figure 7 respectively.

Table 7. Spatial variation of soil texture

Soil Texture	Area (Km^2)	Area (%)
Fine	65.77	56.7
Fine Loamy	37.21	32.08
Coarse Loamy	11.9	10.26
Sandy	1.12	0.96
Block Total	**116**	**100**

6.2 Soil Suitability for Crops

In this study, two important cereal crops namely rice and wheat are taken for analysis purpose. The study area is mainly a land of agriculture. An area of about 116.00 sq. km is delineated as agricultural land (Figure 3). The area under different suitability classes and the results are discussed below.

6.2.1 Rice

Suitability analysis for rice indicates that about 13.70% of agricultural area is suitable for rice cultivation and out of which 12.71%, 0.89% and 0.22% are highly (S1), moderately (S2) and marginally suitable (S3). The remaining area (86.30%) is not suitable for rice cultivation among which about 6.82% and 79.48% area are placed under N1 and N2 classes respectively. The unbalanced NPK ratio and the low availability of OC are the major limitations. The spatial extent of different suitability classes for rice cultivation is given in Table 8 and Figure 8.

6.2.2 Wheat

Despite of diffused cultivation in the world, wheat appears to be less cultivated crop due to unsuitable pedological conditions in the study area. In fact the classes NI and N2 reach a percentage of about 91.66% of total agricultural area. The class S1 corresponds to 7.78% of the total agricultural land whereas 0.21% and 0.35% of agricultural land fall under S2 and S3 classes (Table 8 and Figure 9). The major limitations faced by wheat cultivation are low OC and high pH.

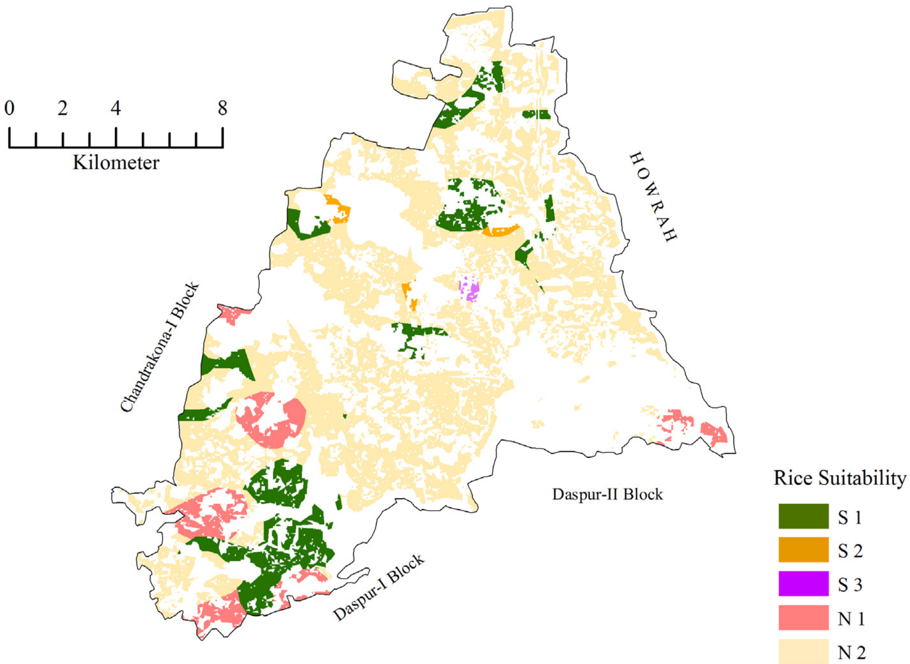

Figure 8. Land suitability zones for rice cultivation

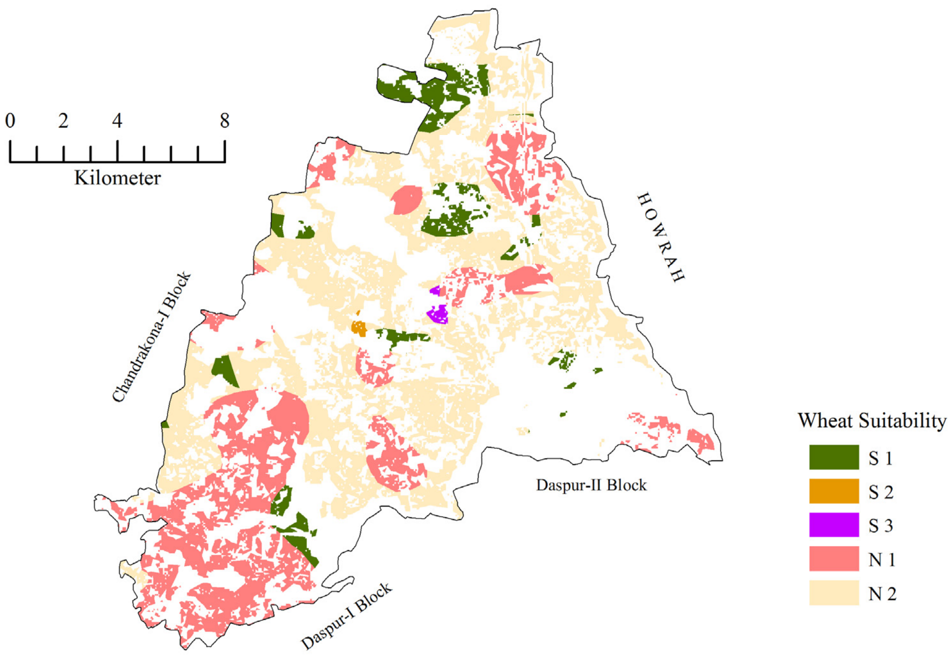

Figure 9. Land suitability zones for wheat cultivation

Table 8. Area under different categories of suitability classes for rice and wheat cultivation

Class	Rice		Wheat	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)
S1	14.74	12.71	9.03	7.78
S2	0.89	0.77	0.24	0.21
S3	0.25	0.22	0.41	0.35
N1	7.91	6.82	33.25	28.75
N2	92.21	79.48	72.97	62.91
Block Total	**116**	**100**	**116**	**100**

7. Conclusions

The land suitability analysis for agriculture is an important piece of information for agricultural development and future planning. Thus a land suitability assessment for two important cereal crops has been conducted in order to help the decision makers as well as agricultural development planners. From the above discussions it is worth to mention that, the study area bears a large coverage of agricultural land but the most of the areas are not suitable for rice and wheat cultivations. This study identifies the major limitations for rice and wheat cultivation. GIS based study can be considered as an essential tool for delineating the land suitability with greater flexibility and accuracy. In the future study this method could be applied for mapping the land suitability at different administrative levels with addition and further refined parameters.

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