Application of GIS and Remote Sensing Techniques in Land Suitability Evaluation for Agricultural Use

Belay Tseganeh[1], Parmjit Singh Sehra[2] and Anil Sood[3]

[1]Researcher, Amhara Regional Agricultural Research Institute, Ethiopia; [2]Professor of Agrometeorology, Punjab Agricultural University, Ludhiana-141004, Punjab, India; and [3]Scientist, Punjab State Remote Sensing Centre, Ludhiana, Punjab, India

Abstract

A study on land use / land cover status and land suitability for important crops of the Balachaur watershed, in Nawan Shahar district of Punjab State, India was carried out using GIS and Remote sensing techniques. Land suitability analysis for important crops of the study area, viz., maize, and wheat was performed based on the limitation concept of the FAO methodology for land evaluation combined with parametric classification approach and multiple overlaying technique in a GIS environment.

The major land use / land cover categories that are identified and mapped are agricultural land, forestland, wasteland, water body and built-up land. About 42 per cent of the watershed is under agricultural land category, 49 per cent is moderately dense forest, 6 per cent is wasteland, while settlements and rivulets cover 3 per cent. The suitability analysis for wheat crop showed that 37, 13, and 50 per cent of the total area of the watershed is moderately suitable, marginally suitable and permanently unsuitable, respectively. With respect to maize crop, 0.7 per cent is found to be highly suitable, 36.6 per cent is moderately suitable, 13 per cent is currently unsuitable, and 50 per cent is permanently unsuitable.

Major limitations of the watershed are found to be low soil fertility, low water holding capacity of soils, erosion hazard on steep slope land units, and inadequate water availability during the intermediate growing period. The study showed that GIS and Remote sensing techniques are powerful tools to integrate various data layers and to assess the potentials and limitations of physical land resources for scientific land use planning and decision supporting systems in crop specific modeling of agricultural production.

Key words: *Land suitability, Land use planning, parametric classification approach, GIS and remote sensing*

1. Introduction

Any land use planning for sustainable development requires identification of the type of the current land use with respect to the socially relevant utilization types and their requirements and comparison of recommended land-utilization types with existing land use. For the purpose of such analysis, a systematic land suitability evaluation is required. Land evaluation is the process of assessment of the potentials and limitations of the land performance when used for specified agricultural uses. It involves the execution and interpretation of land resources surveys and studies of land form, soil and climatic factors in order to identify and make a comparison of most promising kinds of land uses.

Land suitability classification is an approach in land evaluation that involves the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. It takes account of important attributes of land and compares them with the requirements of the crops to give a picture of the potentials and constraints of the land for crop production. The approach allows creation of unique ecological land units or agro-ecological cells within which optimum land decision can be made. Delineating land units into homogeneous suitability classes is an effective way of allowing the users and decision makers to see at glance which areas are highly suitable, moderately suitable, marginally suitable or unsuitable for a given land utilization or crop production.

Recently, geographical information system (GIS) and remote sensing techniques have showed advancement and provide greater benefits in mapping and monitoring of natural resources. Remote sensing is the science of acquiring information about an object or feature from a measurement made at a distance without making physical contact with an object or feature under investigation, while GIS is a decision support system involving the interaction, analyzing and displaying spatially referenced data in a problem solving environment. Many of conventional approaches of handling multi thematic information to arrive at optimal solutions and rational decision-making are being computerized using geographic information system. The powerful query, analysis and intervention mechanism of GIS makes it an ideal scientific tool to apply it for land use planning.

Therefore, the objectives of this study were, to assess and analyze the suitability of land for major crops (land utilizations) of the study area, to delineate the watershed into homogenous agro-ecological cells or land units and to apply GIS and remote sensing techniques in land suitability analysis and to generate land use and land suitability maps.

2. Materials and Methods

The study area, Balachaur watershed, is located between 31^0 10' N latitude and 76^0 10' to 76^0 25' E longitude in Nawan Shahar district of Punjab State, India. It covers an area of 2082 ha at an altitude of about 355 meters above sea level. The area receives annual rainfall of about 1129 mm. The maximum and minimum temperatures are $30C^0$ and $16C^0$ respectively and the mean annual temperature is $23C^0$.

IRS1D-LISS-III imagery (Fig 1.) was visually interpreted to identify land use categories of the watershed and land suitability analysis was performed based on the limitation concept as described in FAO guideline and framework for land evaluation combined with parametric classification approach. This involved overlaying of two basic information layers i.e. land use requirements and land qualities. Rain fed maize and wheat are identified as the main land utilization types of the study area. Land use requirements of these crops were reviewed from various publications mainly from FAO (1983), FAO (1996), Sys (1993), Sehgal (1996) and Sarkar (2003).

Land suitability evaluation model for each crop was defined by a land suitability index, which is a combined soil-climate index, computed as the product of the individual rating values of all land qualities (diagnostic factors multiplied by 100) i.e. land suitability index = A x B x C x. ……x 100. (A, B, C are rating values of diagnostic factors). Multiple overlay operation using ARC/INFO GIS was applied to generate resultant polygonal layers from the thematic layers of diagnostic factors. The land suitability evaluation model was applied to the resultant polygonal layers. The values obtained from the model are matched with a pre-defined land index-scoring table (Table 1), which provided the final suitability class of each land unit for each crop type.

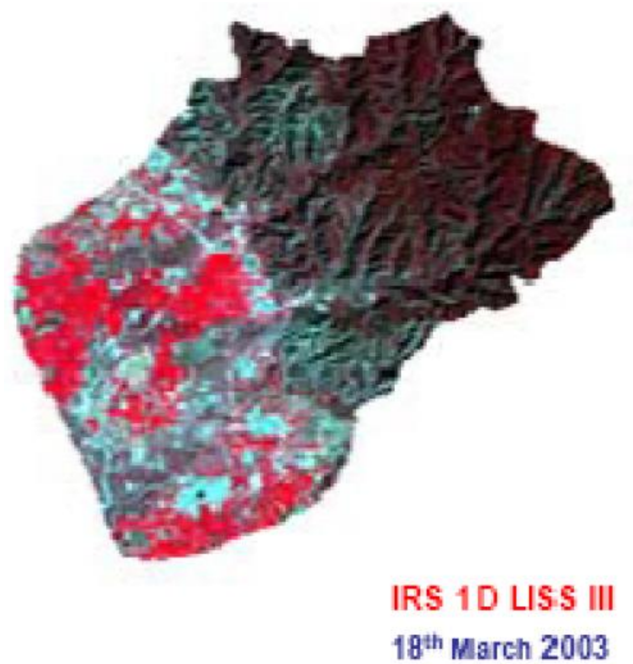

Fig. 1 False Color Composite (FCC) of Balachauer watershed (describe the different colors of the image)

Table 1: Land index scoring for suitability classification

Land Suitability index	Suitability class	Description
75-100	S1	Highly suitable
50-75	S2	Moderately suitable
25-50	S3	Marginally suitable
12-25	N1	Currently not suitable
0-12	N2	Permanently not suitable
-	NR	Not relevant

3. Results and Discussion

3.1 Land use /Land cover status of the watershed

Visual interpretation of satellite image (IRS-1D LISS-III) data provided current information about the land use /land cover status of the watershed. The major land use /land cover categories that are identified out map id e d are te□ r citrt(land . fo et

This land use/land cover category consists of seasonal streams /choe. It constitute about 0.84 per cent of the watershed.

Table: 2 Land use/land cover classes and area statistics (Balachauer Watershed)

Land use/ land cover status			Area (ha)	Per cent of total area
	LEVEL I	**Level II**		
1.	Agricultural Land	1.1 Crop Land	872.36	41.9
		1.2 Plantation	8.77	0.42
2.	Forest Land	2.1 Moderately dense	1028.6	49.40
3.	Waste Land			

The sub-mountain tract of Punjab and the adjoining undulating piedmont plains in the south of Siwaliks locally known as the Kandi Zone covers the watershed. The Siwalik Hills cover about 1028.6 hectares of the watershed and the piedmont plain and choes constitute about 1032.9 and 17.5 hectares of the area respectively. Topographically, about 13 per cent of the area has gentle slope, 37 per cent has nearly level to gently slope and 49 per cent of the area is under steep to very steep slope category. Due to the topography and lithological constraints, the irrigation facilities are not available and hence crop production is being carried out under rainfed conditions.

Fig. 3 Physiographic map of Balachauer watershed

3.3 Edaphic factors

The soil textural class of the watershed ranges from fine to coarse soils. About 265.8 ha of of well to moderately well drained, which are associated with the sandy loam, loam, and silt loam classes. In moderately well drained soil classes, water is supposed to be removed moderately slowly to readily slowly to keep the sub soil wet for a sufficient part of the growing season. While in well drained soil classes, water is expected to be removed from the soil readily but not rapidly and hence soils have intermediate available water storage capacity.

Assessment of rooting conditions in terms of effective soil depth indicate that 49 per cent of the watershed area has shallow to medium deep soils and the rest has very deep soils. The soil depth determines the volume of the soil, which the roots can exploit for plant growth. Nutrient availability and retention capacity are assessed through soil reaction and organic carbon contents of the soil resources. Soils are said to be normal when it is slightly alkaline in pH and the organic carbon content is low to medium, calcium carbonate is either absent or present in a very small amounts.

Fig.4 shows a generalized soil resources map of the watershed (study area). The watershed is classified in to six soil mapping units / land units (Table 3). Land unit which is a term of convenience to cover any unit of land used for evaluation, is applied in this text instead of soil mapping unit. A land unit is defined as an area of land, usually mapped, with specified characteristics and employed as a basis for land suitability evaluation. Examples of land units employed in evaluation for rainfed agriculture are land system, soil series, soil association and other soil-mapping units (Dent and Young 1981).

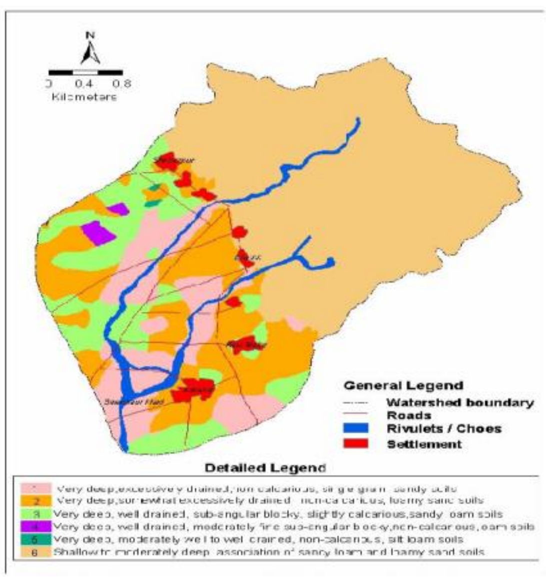

Fig.4 Soil resources map of Balachauer watershed

3.4 Agro-climatic resources

Water availability and temperature regime are the most important land qualities related to the agro-climatic environment of rainfed agriculture which have significant influence on suitability and adaptability of crops of the study area. The concept of the growing period and water balance is used as a framework to assess the potentials of these climatic resources.

Growing Period

The length of the growing period, which is expressed in terms of the major climatic factors, viz., temperature, rainfall and evapotranspiration, provides a realistic simulation of the crop growth cycle. The length of the growing period indicates the period of the year when moisture and temperature conditions are favourable for crop growth. It is determined by a water balance model, which compares rainfall with potential evapotranspiration (Fig. 5).

The time when rainfall equals or exceeds half of the potential evapotranspiration is the beginning of the growing period and the time when the rainfall decreases and falls below half the potential evapotranspiration is considered as end of the growing period. Therefore length of the growing period indicates the period during the year when precipitation exceeds half the potential evapotranspiration provided that the prevailing temperature is conducive to crop growth (mean temperature $\geq 5^oC$). Two growing periods namely intermediate and normal growing period are identified in the study area.

Intermediate growing Period

The intermediate growing period starts in December and extends up to the first week of March. In the intermediate growing period, precipitation does not exceed the full evapotranspiration which implies that there will be no surplus of soil moisture but since it exceeds half of the potential evapotranspiration, crop production is still possible with a narrow range of available moisture period. The total amount of the rainfall and potential evapotranspiration during this period is 144 mm and 265 mm respectively which shows moisture deficit of about 121 mm. But assessment for the distribution shows that the rainfall amount for each standard meteorological week (SWM) during the intermediate growing period is slightly higher than half of the potential evapotranspiration amount of the corresponding meteorological weeks. The highest monthly rainfall amount during the intermediate growing period is about 41 mm in February and the corresponding half potential evapotranspiration is 38.5 mm. The mean temperature during this period is found to be 15^oC with maximum temperature of 27^oC during the 10^{th} standard meteorological week and minimum temperature of 4.7^oC during the 3^{rd} standard meteorological week. This shows that mean temperature is not a constraint for crop production during this period as it is above the base mean temperature ($>5^oC$).

Even though, it is possible to cultivate less water consuming crops during the intermediate growing period of the study area, the precipitation is still lower than the potential evapotranspiration which implies the fact that the full water requirement of crops can not be satisfied with the available rainfall resource. Therefore, crop production during the intermediate growing period of the study area is being carried out under insufficient available water condition which leads to a reduction of the maximum attainable yield potential of the crops.

Normal Growing Period

The normal growing period starts during the 26th standards meteorological week (last week of June) and extends till the 38th meteorological week (end of September). The total rainfall amount during this period is 843 mm and the potential evapotranspiration is 403 mm. From the total rainfall and corresponding potential evapotranspiration demand during the normal growing period, it can be concluded that it is a humid period when the available water resources exceeds the crop water requirement. The highest rainfall of the period occurs in July and August, which have rainfall amount of 319 mm and 322 mm respectively while the maximum water demand during the same growing period is in July, which has potential evapotranspiration of 116 mm. The mean temperature during the normal growing period is 29^{o}C with maximum temperature record of 36^{o}C during the 26th SMW (last week of June) and minimum temperature of 20^{o}C during the 39th SMW (last week of September). Since the rainfall exceeds the full potential evapotranspiration and the mean temperature is higher than the base temperature value (>5^{o}C), the normal growing period can be considered as conducive and suitable for crop production keeping other environmental conditions constant.

The climatic water balance of the area also indicates that it accumulates potential evapotranspiration (PET) of 1308 mm annually with rainfall of 1129 mm, which implies water deficit of 179 mm. During the monsoon season (July, August and September), however, the rainfall exceeds the potential evapotranspiration and hence the annual water deficit will occur during the remaining period of the year.

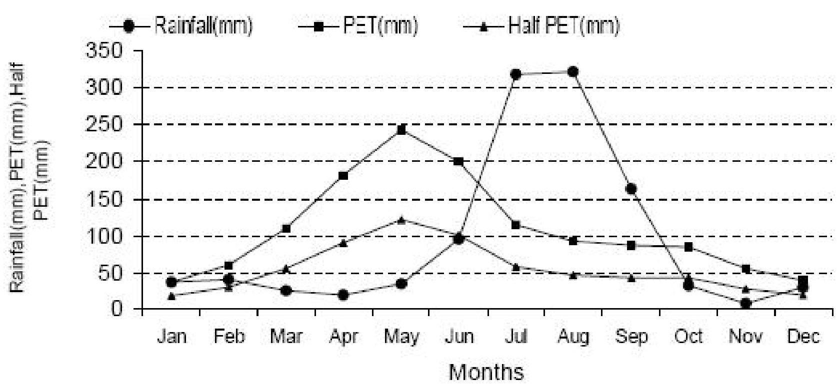

Fig. 5 Growing period at Balachauer watershed

3.5 Land suitability assessment for major crops

Land suitability assessment for important crops of the study area, viz., maize, wheat and mung bean was made following the FAO methodology of land evaluation for rainfed agriculture. This involved comparison of the inherent land qualities with the land use requirements of the crops. The land suitability assessment is expressed in terms of suitability ratings based on how far the land qualities meet the crop requirements. The land suitability rating is derived from the degree of limitations of each land quality. The land suitability rating, therefore, indicates the partial suitability of a given land unit for the specified crop type based upon consideration of one land use requirement and its corresponding land quality. Combining the suitability ratings of individual land qualities by means of a land suitability index provided the overall /final suitability class of a land unit for each crop under consideration. The degree of suitability of each land unit for the given crops is indicated by different levels of suitability, namely, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently unsuitable (N1) and permanently unsuitable (N2). A rating of S1 indicates that the land quality is optimal and suppression of potential yield is assumed to be slight. Ratings of S2 and S3 indicate that the land qualities are sub-optimal for crops and potential yield would be suppressed.

Land suitability for Maize

The final suitability analysis showed that the watershed is divided into four levels of suitability, viz; highly suitable (S1), moderately suitably (S2), currently unsuitable (N1) and permanently unsuitable (N2) with respect to the climatic and soil requirements of the maize crop and the potentials of the inherent land qualities (Fig. 6). These land suitability classes constitute 0.7, 36.3, 12.8 and 49.4 per cent of the watershed area, respectively. In terms of area coverage, highly suitable area constitute of Major limiting factors for this crop are found to be topography (slope), erosion hazard and soil texture.

Table 4: Land suitability index and overall suitability of Balachaur watershed for maize

Land unit	Land suitability index	Degree of suitability	Designation of suitability class
1	22.16	Currently unsuitable	N1
2	63.25	Moderately suitable	S2
3	74.41	Moderately suitable	S2
4	87.54	Highly suitable	S1
5	83.17	Highly suitable	S1
6	7.50	Permanently unsuitable	N2

Table 5: Maize suitability area under different classes

Suitability class	Area (ha)	Percentage of total area
Highly suitable (S1)	15.3	0.7
Moderately suitable (S2)	754.8	36.3
Currently unsuitable (N1)	265.8	12.8
Permanently unsuitable (N2)	1028.6	49.4
Non-relevant (NR)	17.5	0.8

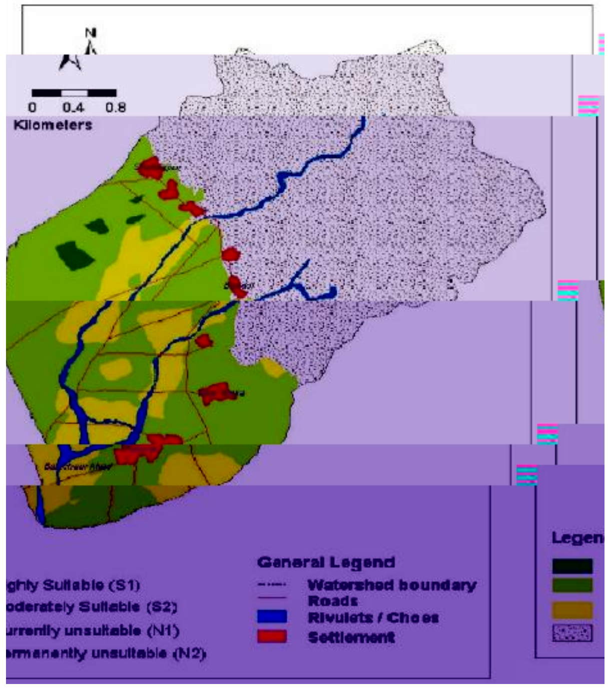

Fig.6. Maize suitability map for Balachauer watershed

Land suitability for wheat

The overall climatic and land resource suitability analysis for wheat indicates that the watershed is divided into three suitability classes namely moderately suitable (S2), marginally suitable (S3) and currently unsuitable (N2), with respect to the land use requirements of the crop. These suitability classes constitute about 13, 37 and 49 per cent of the total area of the watershed respectively. The land suitability map for wheat which is generated in a GIS environment by multiple overlaying techniques of various thematic layers of the land qualities and reclassified based on the values of the land suitability index is shown in Fig. 7. Major limiting factors for this crop are found to be topography (slope), erosion hazard, water availability, soil depth and organic carbon content.

Table 6: Land suitability index and overall suitability of Balachauer watershed for wheat

Land unit	Land suitability index	Degree of suitability	Designation of suitability class
1	38.06	Marginally suitable	S3
2	57.14	Moderately suitable	S2
3	63.31	Moderately suitable	S2
4	63.31	Moderately suitable	S2
5	60.14	Moderately suitable	S2
6	9.38	Permanently unsuitable	N1

Table 7: Wheat suitability area under different classes

Suitability class	Area (ha)	Percent of total area
Moderately suitable (S2)	770.1	37
Marginally suitable (S3)	265.8	12.8
Permanently unsuitable (N2)	1028.6	49.4
Non relevant (NR)	17.5	0.8

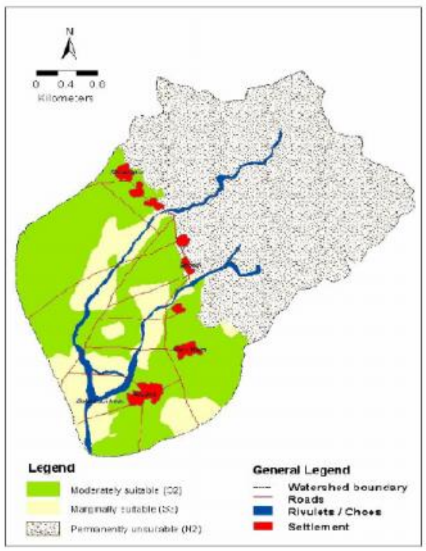

Fig. 7 Wheat suitability map of Balachauer watershed

Conclusion

The productivity potential of an area can only be realized when crop production decisions are based on adequate characterization of the inherent variables of land mainly climate, soil and land form. Sustainable and maximum production can be achieved when the land user knows the potentials and limitations of these natural resources and take appropriate farm management decisions. This study was, therefore, conducted to assess land suitability for important crops of the study area with respect to potentials and constraints of the land qualities using the potential application of GIS and remote sensing techniques.

The current land use / land cover status of the study area was studied by visual interpretation of the satellite image. The major land use / land cover categories that is identified and mapped are agricultural land forest land, wasteland, water body and built up land. Assessment for agroclimatic potentials of the area with respect to growing period and water balance showed that it has experienced two growing periods, namely, intermediate and normal growing periods. The intermediate growing period starts in December and extends up to the first week of March. The precipitation is lower than the potential evapotranspiration and hence the full water requirements of crops cannot be satisfied with the available water resources. Crop production during the intermediate growing period is, therefore, being carried out under insufficient available water condition which leads to a reduction of the maximum attainable yield potential of crops. The normal growing period starts during the 26th standard meteorological week (last week of June) and extends up to the 39th meteorological week (end of September). During this period, the rainfall exceeds the potential evapotranspiration demand and hence it is a humid period when the available water resource exceeds the crop water requirement leading to loss of surplus of water by means of surface runoff. Monthly climatic grouping of the area based on moisture index also revealed that 2 months (July and August) are extremely wet and 3 months (April, May, and November) are extremely dry, while other months are under semi moist to dry condition.

The land suitability assessment for important crops of the study area, viz., maize and wheat was carried out following the FAO methodology for land evaluation. The methodology involved integrating climate, soil and crop information in the process of matching the land use requirements of the crops with the properties of mapped land units by means of the inherent land qualities and characteristics. The suitability analysis for wheat crop showed that 37, 13, and 50 per cent of the total area of the watershed is moderately suitable, marginally suitable and permanently unsuitable with maximum attainable yield of 57 to 63, 38 and 9 per cent respectively. With respect to maize crop production, only 0.7 per cent of the total area is found to be highly suitable with productivity potential of 83 to 87 per cent. About 36.3 per cent of the area is found to be moderately suitable, 12.8 per cent is currently unsuitable, while 50.2 per cent is permanently unsuitable.

The major limitations of land qualities of the watershed are found to be related with low nutrient availability of soils, low water holding capacity, erosion hazard on steep land units, and inadequate water availability during the intermediate growing period. This study furthermore showed that GIS and remote sensing techniques are powerful tools for integrating various data layers (climate, soil and crop information), and to assess the potentials and limitations of the physical land resources for improved scientific land management planning and decision supporting system in crop specific modeling of agricultural production.

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