

# Use of Remote Sensing and GIS Technology in Sustainable Agricultural Management and Development

## Indian Experience

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### 1. Abstract

Agricultural sustainability has the highest priority in all countries, whether developed or developing. Aero-space Remote Sensing and GIS technology are gaining importance as useful tools in sustainable agricultural management and development. This paper discusses the integrated use of Remote Sensing and GIS technology in several areas for sustainable agricultural development and management in India, with case examples.

### 2. Introduction

The solution for providing food security to all people of the world without affecting the agro-ecological balance lies in the adoption of new research tools, particularly from aerospace Remote Sensing, and combining them with conventional as well as frontier technologies like Geographic Information Systems (GIS). Sustainable agricultural development is one of the prime objectives in all countries in the world, whether developed or developing. The broad objective of sustainable agriculture is to balance the inherent land resource with crop requirements, paying special attention to optimisation of resource use towards achievement of sustained productivity over a long period (Lal and Pierce, 1991). Sustainable agricultural development/ sustainable increase in crop production could be achieved by adopting a variety of agricultural technologies, which may be summed up as:

- Improved crop management technology through the use of high yielding, input responsive and soil, climatic and biotic stresses - tolerant crop varieties;
- Suitable cropping systems for different agro-ecological regions based on soil, terrain and climatic suitability;
- Integrated nutrient management for improving soil productivity and minimization of the risk of pollution of soil, water and environment;
- Integrated pest management for effective pests control as well as to reduce the adverse effects of pesticides on environment;
- Soil and water conservation for controlling soil degradation and improving moisture availability.
- Input use efficiency maximization in terms of economic return with minimal input.

### 3. Applications of Remote Sensing and Gis Technology in Sustainable Agricultural Management and Development (Case Examples from India)

Remote sensing and GIS technology are being effectively utilized in India in several areas for sustainable agricultural development and management. The areas of sustainable agricultural development/ management include cropping system analysis; agro-ecological zonation; quantitative assessment of soil carbon dynamics and land productivity; soil erosion inventory; integrated agricultural drought assessment and management and Integrated Mission for Sustainable Development (IMSD). Use of Remote Sensing and GIS technology in these areas of sustainable agricultural management and development are discussed for Indian case examples in the following sections:

#### 3.1 Cropping System Analysis

Information on existing cropping systems in a region with respect to areal extent of crops, crop vigours/ yield and yearly crop rotation / sequence practices is important for finding out agricultural areas with low to medium crop productivity where sustainable increase in crop production can be achieved by adoption of suitable agronomic management packages including. introduction of new crops etc. GIS technology can play a vital role in cropping system analysis of an area by spatially integrating temporal crop inventory information of various crop seasons of that area.

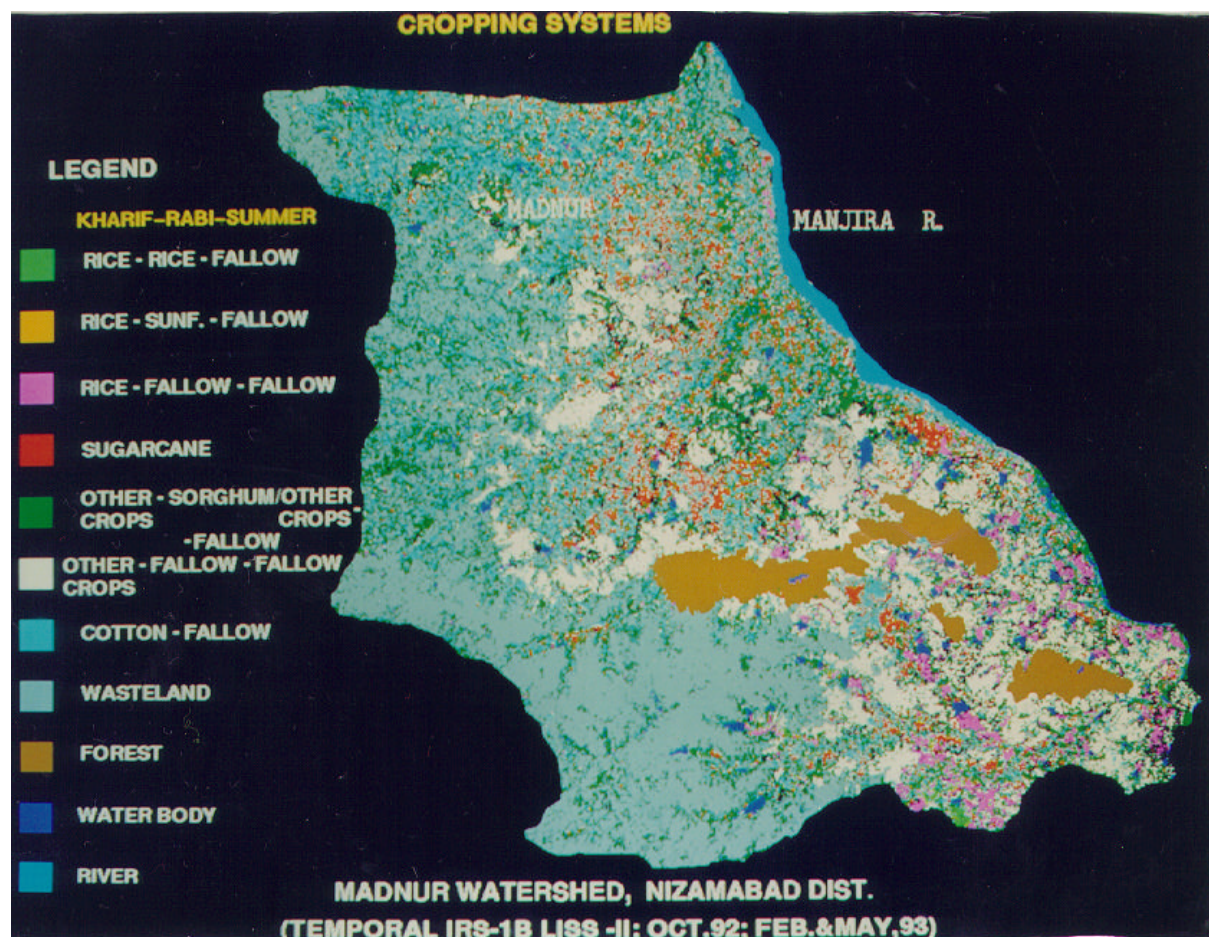


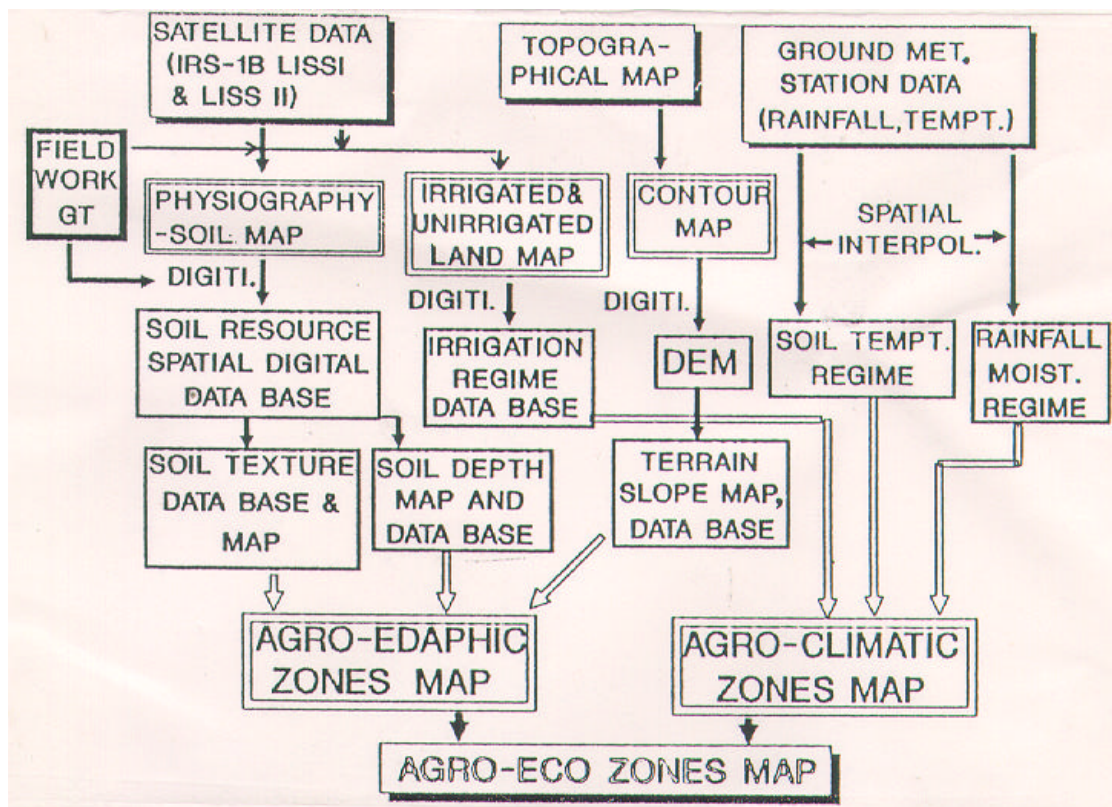
Figure.1. Cropping system map generated through integrated use of temporal digital satellite data and GIS.

Figure.1 shows the spatial distribution of various cropping systems/ sequential cropping pattern, which is the final result of a cropping system analysis case study carried out in Southern India (Madnur Watershed, Nizamabad district, Andhra Pradesh). The cropping system analysis was carried out by GIS aided integration of multi-temporal digital satellite (IRS-1B; LISSII) data based classified crop inventory information of the Kharif ( Rainy season), Rabi (winter) and summer crop seasons (ASD, 1995). The results of this study are summarized in the Table-1.

**Table-1. Major cropping systems and their areal distribution in the watershed**

Cropping System	% of Watershed Area	Agricultural Productivity
Single Season Crop (Rice/Sorghum/Rainfed crops)	52.0	Low
Two seasons crop (Rice, Sunflower, Rainfed crops)	6.0	Medium
Three seasons crop (Sugarcane, Cotton, Rainfed crops)	4.0	High
Non-agriculture (Wasteland, Forest, Water Bodies)	38.0	---

The results indicate that 52% of the study area has low agricultural productivity with one season under crop (rice or sorghum or rainfed crops) out of every three crop seasons.. Only 10% of the area have medium to high agricultural productivity with under two crops or under almost perennial sugarcane. Most of the watershed does not have irrigation facilities and hence rainfed single crop grown once out of three crop seasons in a year is the major system of farming in the area.



**Figure 2. Flow diagram of the methodology of agro-ecological zoning using Remote Sensing and GIS.**

### 3.2 Agro-Ecological Zone based Land Use Planning

Agro-ecological zoning (AEZ) is an important basis of sustainable agricultural land use planning of a region. AEZ encompasses the delineation of landscapes into regions or zones that are broadly homogeneous with respect to agro-climate, soils and terrain characteristics and are also relatively uniform with respect to crop production possibilities. GIS technology is very useful for automated logical integration of bioclimate, terrain and soil resource information which are required for delineating AEZ in a region. Fig. 2 illustrates a Remote Sensing and GIS based methodology developed for AEZ using satellite (IRS-1B: LISS I & II) derived soil, land use and irrigation regime maps, DEM derived slope and ancillary data of land characteristics and agromet as inputs (Saha & Pande, 1996).

Eleven Agro-Ecological Zones (Fig.3) were delineated in a case study of the Doon Valley (Dehradun district, Uttar Pradesh) by GIS aided integration of "Agro-climate" and "Agro-edaphic zones map layers.

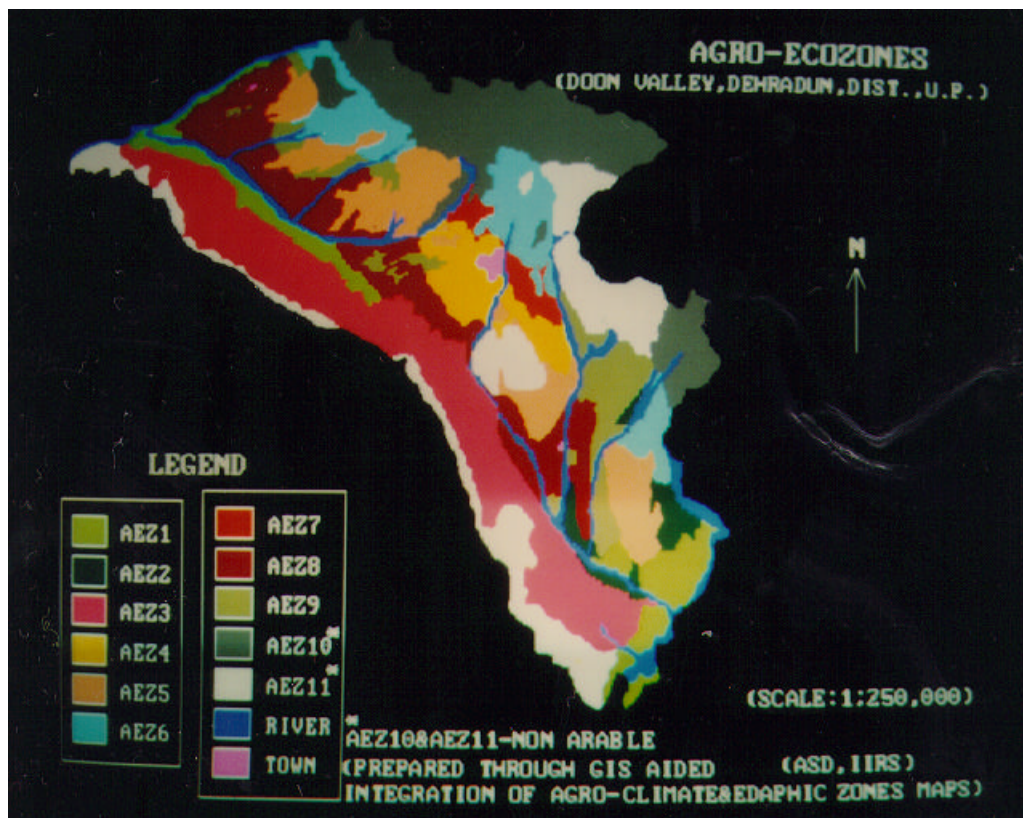


Figure 3. Agro-ecological zones map of Doon Valley prepared by integrated use of satellite data and GIS.

The sustainable agricultural land use plan of the area was suggested on the basis of AEZ characteristics and is summarized below (Table-2).

**Table-2. Description and spatial extent of agro-ecological zones in Doon Valley**

Agro-ecological Zone	Description		Suggested Sustainable Agri culture & other Landuses	% of Total area
	Agro-edaphic Characteristic	Agro-climatic Characteristic		
AEZ1 & AEZ8	Deep to very deep, fine loamy, coarse loamy, 1-3% slope	Rainfall: 160-180 cm Thermic, Irrigated	Intensive crop production (Wheat/Paddy & Sugarcane)	17.9
AEZ4	Deep, fine loamy, 3-4% slope	Rainfall: 160-180 cm, Thermic, Irrigated	Intensive corp production (Wheat & Paddy)	3.8
AEZ7	Moderately deep, coarse loamy, 4-8% slope	Rainfall: 160-180 cm Thermic, Unirrigated	Rainfed double cropping (Wheat & Maize/Sorghum)	1.5
AEZ6	Moderately deep, coarse loamy/fine loamy, 8-15% Slope	Rainfall: 160-180 cm Thermic, Unirrigated	Rainfed cropping (Wheat & Pasture/fallow)	7.0
AEZ2,3,5 & 9	Presently under good forest covers		Protection from Biotic pressure	34.8
AEZ 10 & 11	Shallow to M. deep, loamy skeletal/coarse loamy, 25 - > 35% slope	Rainfall: 160-220 cm, Thermic/mesic, Unirrigated (Non-Agril)	Non arable (Afforestation & Grazing)	28.3

### 3.3 Soil Erosion Inventory

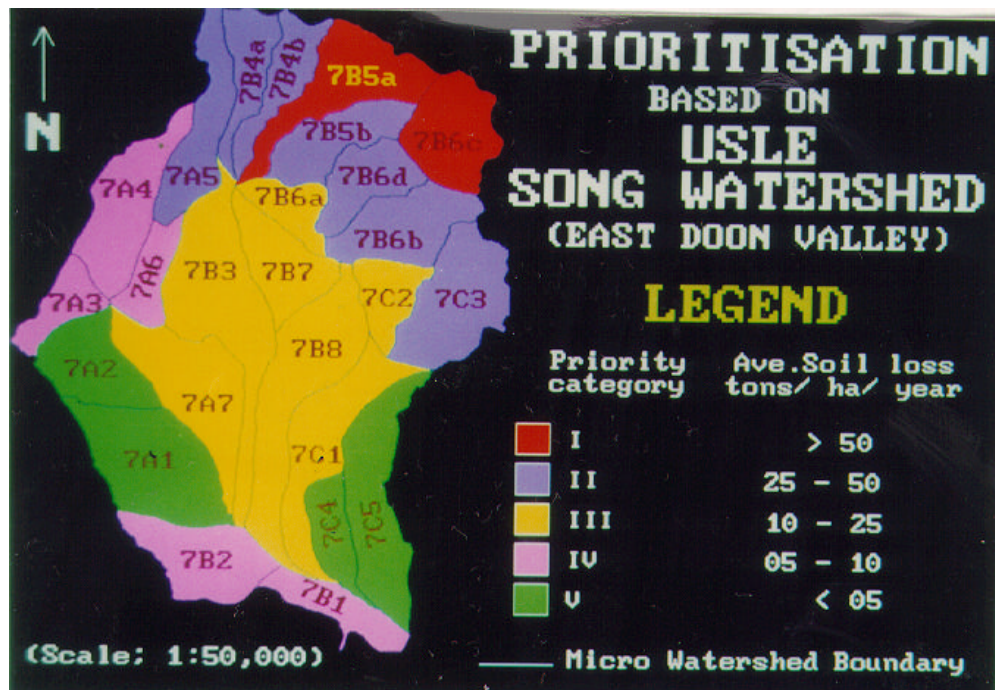
The information on soil erosion such as quantification of erosional soil loss and soil conservation prioritization of watersheds/ sub watersheds provides vital inputs for sustainable agricultural management with respect to soil conservation. Remote Sensing and GIS techniques are being effectively used in India for preparation of soil erosion inventories by integration of physiography, soils, landuse/ land cover, slope map layers and use of ancillary data of agro-met and soil physico-chemical properties (Saha & Pande,1994 and Saha, 1996). In one such case study of a watershed in Northern India (Song Watershed, Dehradun District, Uttar Pradesh) (ASD, 1996), satellite (IRS-1B, LISS-II) analyzed soil, landuse/ land cover, drainage, DEM generated slope and slope length and ancillary agromet and soil characteristic data were used to assess erosional soil loss according to Universal Soil Loss Equation (USLE) in a GIS environment. The basic equation of the USLE model is -

$$A = R.K.LS.C.P$$

Where:

**A** is estimated soil loss (t/ha/year); **R** is rainfall erosivity factor; **K** is Soil erodibility factor; **LS** is slope and slope length factor; **C** is landcover factor and **P** is conservation practice factor.

Figure 4 illustrates the results of this case study involving a soil erosion inventory of 25 micro watersheds belonging to this watershed for soil conservation measures for sustainable watershed development on the basis of estimated micro-watershed wise area weighted average erosion soil loss data.



**Figure 4. Soil conservation priority map of micro watersheds based on GIS analysed area weighted average estimated soil loss.**

### 3.4 Soil Carbon Dynamics and land Productivity Assessment

By studying the carbon dynamics of agro-ecosystems it is possible to quantify fixation and release of carbon in the soil-crop-plant system. This knowledge is essential for assessing organic matter depletion of soil, long-term soil fertility and sustained productivity of agro-ecosystems. An integrated Remote Sensing and GIS based methodology was developed for studying carbon dynamics such as annual crop Net Primary Productivity (NPP), soil organic matter decomposition and the annual soil carbon balance using models such as the Osnabruck - Biosphere and Century models (Saha and Pande, 1994). According to Osnabruck - Biosphere model

$$NPP = f [NPP_i, F_s, F(CO_2)]$$

Where:

NPP<sub>i</sub> is Climatic ( Rainfall, Temperature) potential NPP; F<sub>s</sub>- Soil factor and F (CO<sub>2</sub>) - nutrition factor of atmospheric CO<sub>2</sub> content to NPP.

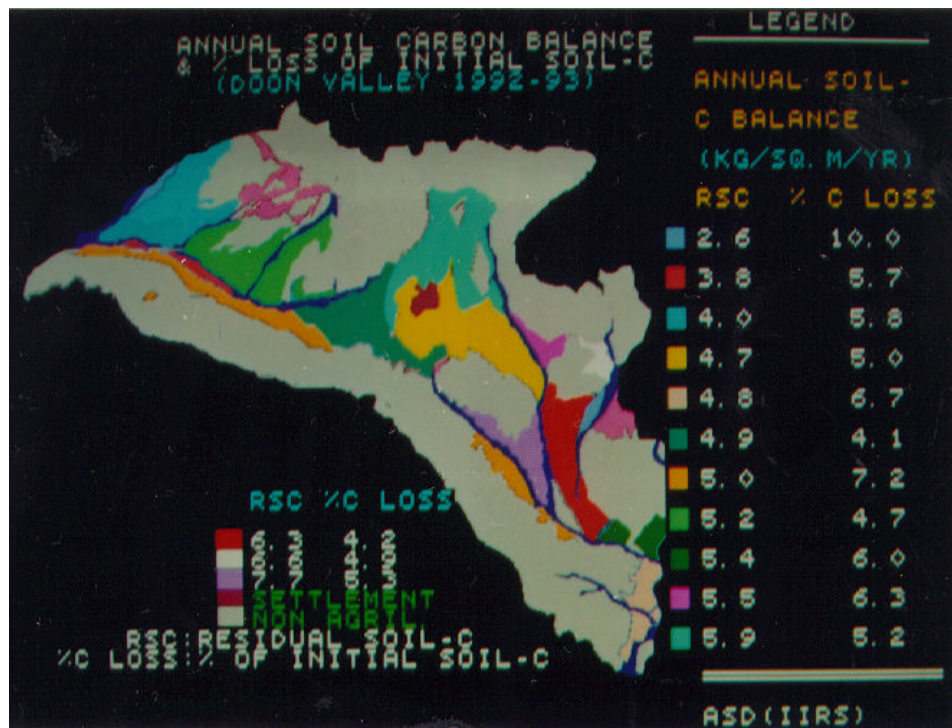
The century model estimates decomposition loss (DL) of soil humus carbon and it is expressed as:

$$DL = f(K_i, T, M_d, T_d, C_i)$$

Where:

K<sub>i</sub> is Maximum decomposition rate, T is Soil (Silt + Clay) content; M<sub>d</sub> and T<sub>d</sub> are Rainfall and temperature factors, respectively, and C<sub>i</sub> is initial soil humus Carbon content.

Multi-temporal satellite data (IRS-1B: LISS-I) derived annual crop biomass, soil map and soil characteristics and ancillary agro-met data were the major inputs used for the soil carbon dynamics study in a case study of Doon Valley (Dehradun district, Uttar Pradesh).



**Figure 5. Spatial distribution of the annual soil carbon balance of the Agro-Ecosystems in Doon Valley prepared through GIS based modeling approach.**

Figure. 5 presents a map of the model estimated annual carbon balance of agro-ecosystems in the study area. The data indicate that annual loss of carbon from agro-ecosystem ranges between 0.21 to 0.42 kg/m<sup>2</sup> (4 to 10% of initial soil organic carbon content of soil). Agro-ecosystems with higher losses of soil organic carbon have to be supplied with more organic manure and crop residues for sustained agricultural productivity.

Quantitative assessment of land productivity is one of the important components of integrated nutrient management for sustainable agricultural development. Land productivity data provide information about the inherent fertility status of soilscapes, which is a useful guideline for supplementing soil nutrients from external sources, such as fertilizers/ manure. In a case study from Jainti Watershed (Bihar), land productivity was assessed and mapped (Fig.6) following the Story Index model by GIS aided integration of soil and slope maps and laboratory measured soil physio-chemical data (Kudrat and Saha, 1993). According to the Storrie Index model, land productivity (LP) is expressed as -

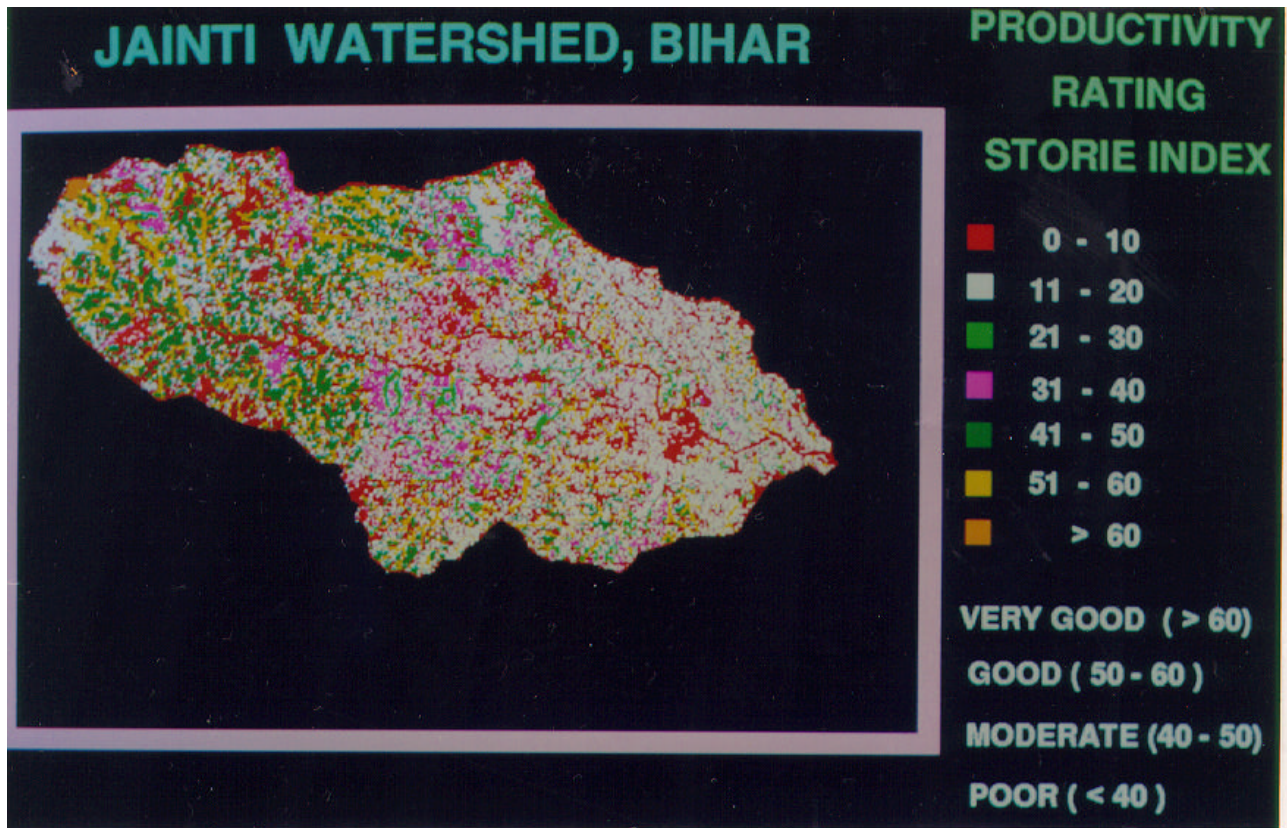
$$LP = f(A,B,C,X)$$

Where, A is a rating based on soil development; B is a rating based on soil texture; C is a rating based on terrain slope and X is a composite rating based on soil fertility, pH, drainage, erosion etc.

### 3.5 Integrated Agricultural Drought Mitigation

An integrated method for agricultural drought mitigation, the National Agricultural Drought Assessment and Monitoring system (NADAMS) operationally used in India (Rao, 1996) forms one of the strategies for sustainable agriculture development. NADAMS integrates NOAA

satellite derived temporal spectral vegetation index(VI) and landuse/ land cover data and ground meteorological station observed rainfall and aridity anomaly with ancillary crop cultural information through GIS, to provide a realistic assessment of agricultural droughts (Fig.7).



**Figure. 6. Land productivity map prepared through Remote Sensing and GIS based integrated analysis.**

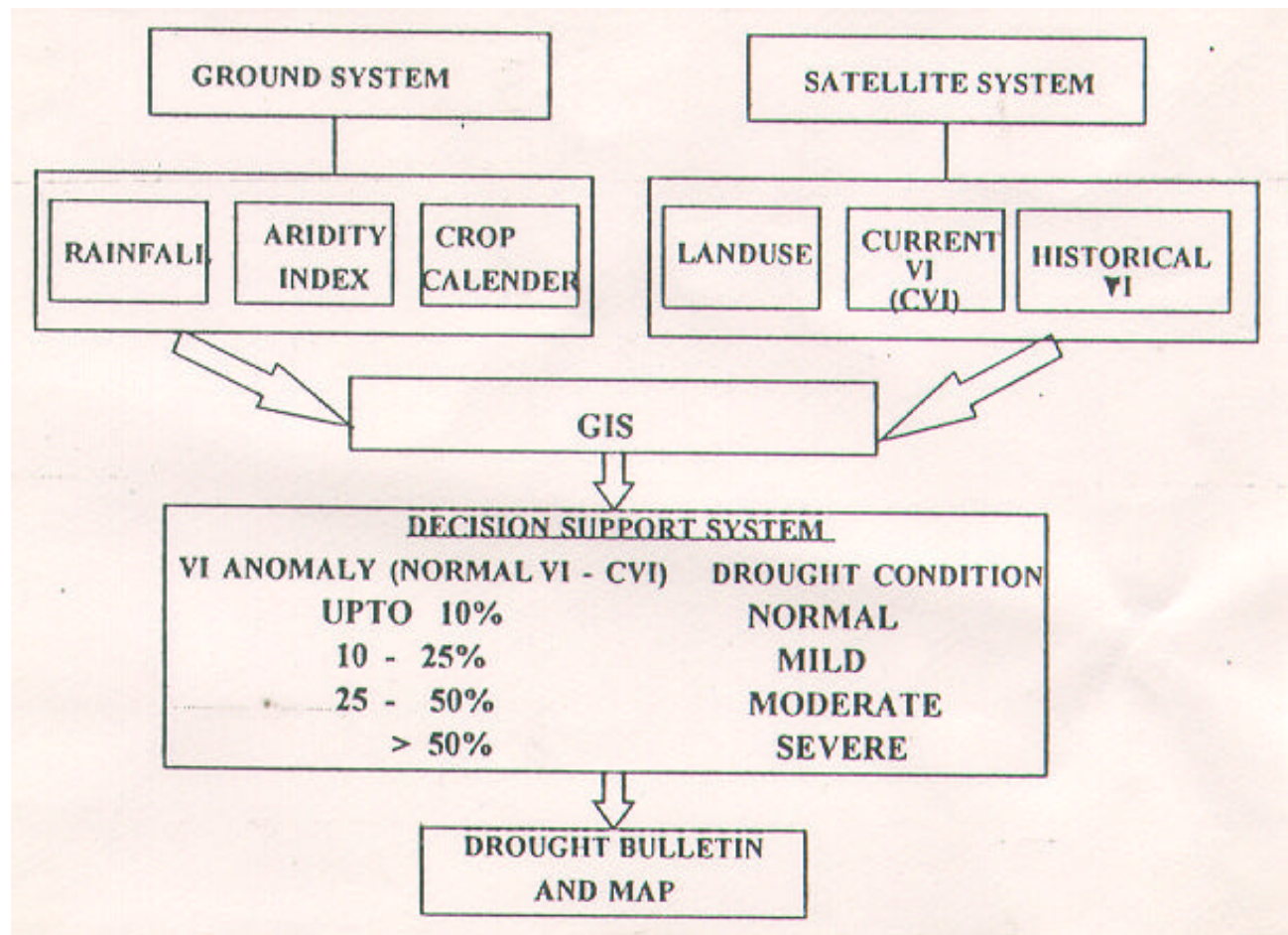
Sustainable agriculture development requires a holistic approach, maximizing the crop yield after taking into account any pre-carious environmental conditions. In this context, the Indian experience of using satellite Remote Sensing and GIS techniques for Integrated Mission for an Sustainable Development (IMSD) becomes relevant. The primary goal of IMSD is to integrate in a GIS environment, information on natural resources derived from satellite Remote Sensing such as soils, landuse/ land cover, slope and surface and ground water potential etc., with relevant collateral socio economic data at each watershed level, to arrive at locality specific action plans for sustainable development (Fig.8, Rao, 1996) .

As one example of IMSD studies, Fig.9 represents action plans generated through integrated analysis for sustainable development of Behta Block (Sitapur District, Uttar Pradesh) .

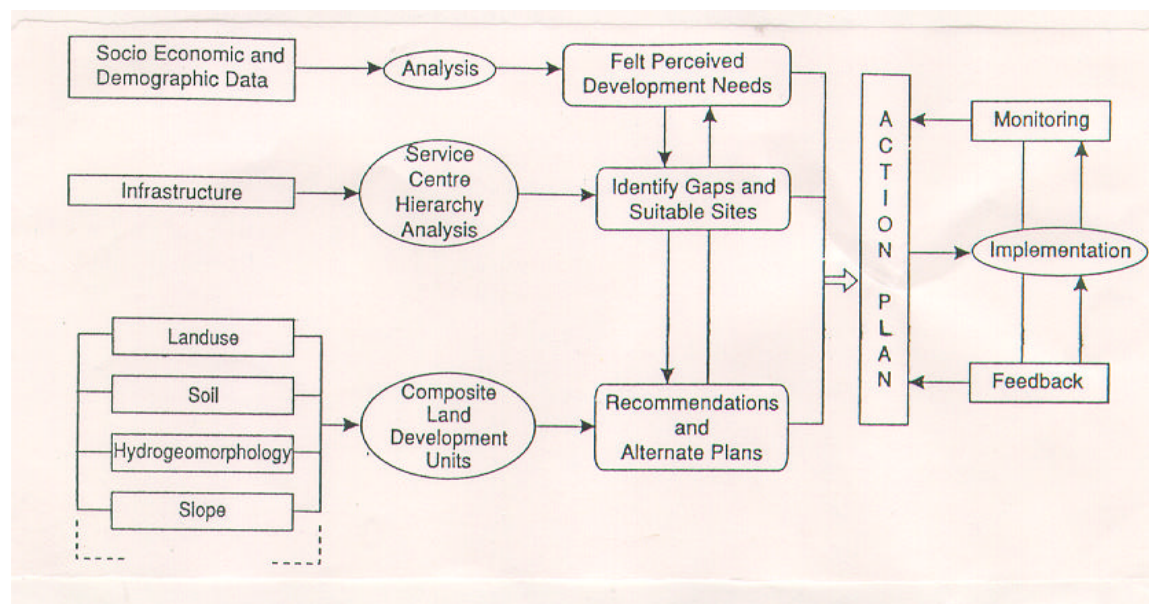
#### **4. Conclusions**

Various studies carried out in several areas of sustainable agricultural management/ development in India by integrated use of aerospace data and GIS have clearly indicated that Remote Sensing and GIS technology are very effective tool for suggesting action plans / management strategies for agricultural sustainability of any region.

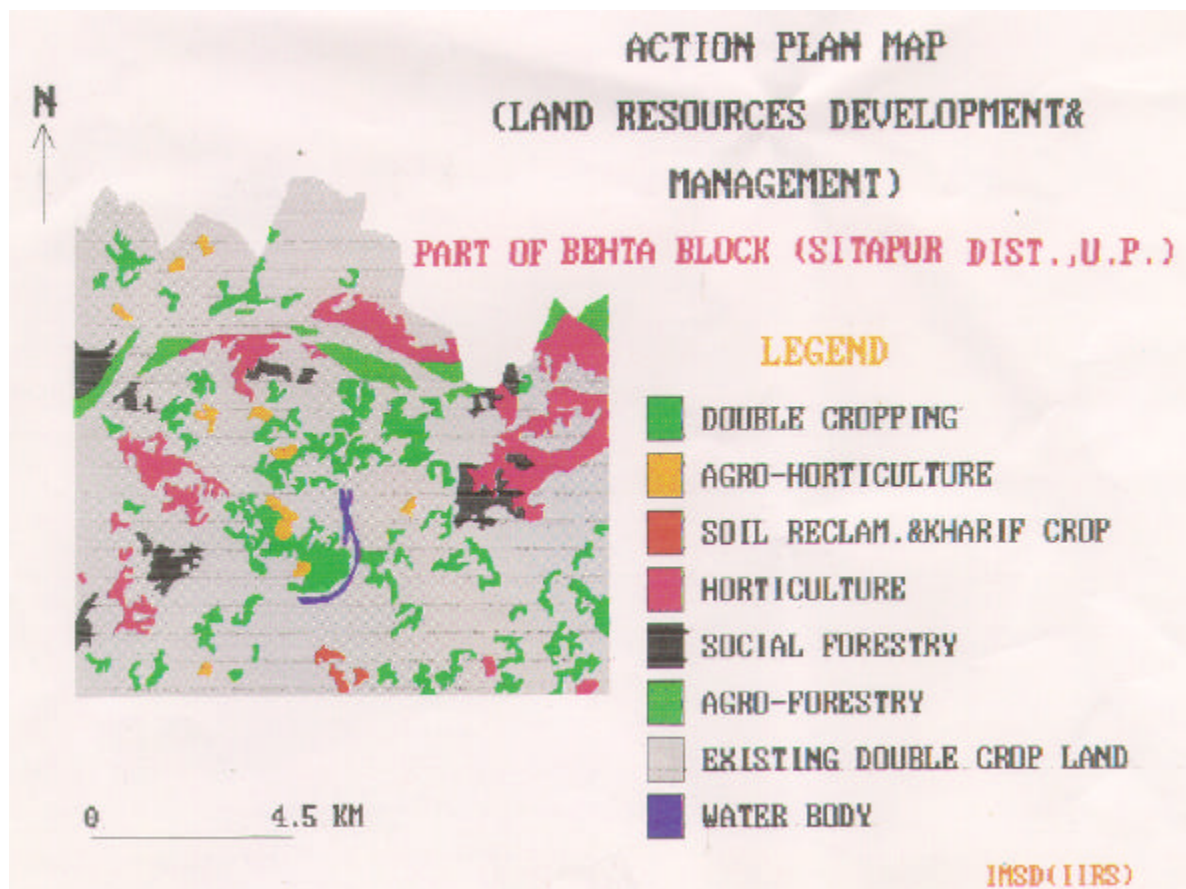




**Figure 7. National Agricultural Drought Assessment and Monitoring System (NADAMS).**



**Figure 8. Flow diagram of methodology of Integrated Mission for Sustainable Development (IMSD).**



**Figure 9. Action plan map for sustainable agriculture development generated through GIS based integrated analysis.**

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