AN APPROACH TO IDENTIFY AREA-SPECIFIC LAND USE ANALYSIS OBJECTIVES

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ABSTRACT:

Maps of land use classes and soil series were analysed to identify areas having specific priorities with respect to agricultural land use analysis under the project Integrated Mission for Sustainable Development (IMSD) in India. IMSD used remote sensing data supported by field investigations to generate land use and soil maps. At present, using GIS techniques, relationships between soils and associated land cover/use are analysed and patterns in these relationships are identified, relationships observed on the basis of *a priori* knowledge of the area and the available statistics are compared and these relationships in the field and through interviews with farmers are correlated. Based on the analysis, three land use analysis objectives have been formulated: Crop Management Improvement, Crop Selection and Conservation. The results can be used to focus the efforts of planning and extension services in the area. The method was tested using a participatory rural appraisal in eighteen villages in which the areas for the three land use analysis objectives were identified. The findings are that the Crop Management Improvement areas require knowledge about sustainable management practices for a specific crop to optimise yield and water use. Areas identified for Crop Selection are mainly occupied by smallholder subsistence farmers with insufficient water for irrigation, and lack of contact with the extension service. In these areas, identifying suitable crops to minimise risk and allow subsistence for the resource-poor farmers may be the priority. In areas identified for Conservation the question should be addressed whether to grow a crop at all, or use the land for alternative activities. The approach identified specific agricultural land use analysis objectives, which match farmers' needs and objectives.

KEY WORDS: Land use; soils; land use analysis objective; Conservation; Crop Management Improvement; Crop Selection; GIS; remote sensing.

1. INTRODUCTION

Biophysical conditions and in particular soil conditions are considered important determinants of land use and receive ample attention, both in land use analysis and in analysis of actual land use patterns (Ravnborg and Rubiano, 2001). Land use refers to a series of operations on land, carried out by humans, with the purpose to obtain products and/or benefits through using land resources (de Bie, 2000). Human resource management strategies, characterized by the arrangements, activities and inputs to produce, change or maintain a desired land cover (Di Gregorio and Jansen, 1998) for arable farming and livestock grazing, significantly influence land use (Nielsen and Zobisch, 2001). Land use, defined in this way, is linked directly to the actions of people in their environment. The general assumption is that land use decisions are primarily driven by socio-economic-cultural considerations of land users. Through experience, often going back generations, farmers have developed land use systems that are well adapted to the potentials and constraints of their land (Cools et al., 2003). It is also assumed that farmers, if they have lived long enough in an area, know the spatial distribution of 'good soils' and the distribution of all soils of different degrees of suitability for production (Messing and Fagerström, 2001). Ravnborg and Rubino (2001) quoting Talwar (1996) and Talwar and Rhoades (1998) state that many studies provide evidence of farmers' detailed knowledge of their soils and of their ability to translate this knowledge into agronomic management options. Hence, where land use systems are being practiced *not* in accordance with the potentials or the suitability of the land, these practices can often be traced back to socio-economic factors as discussed by FAO (1976) and Rossiter and van Wambeke (1993). This is also in agreement with Daba's (2003) observation that in addition to climate, inherent soil properties, topography, vegetation cover and other environmental factors, the socio-economic conditions of farmers can play a significant role in preventing or promoting land degradation. Understanding the relations between socio-economic factors, human use of the land resources and their degradation is essential for the development of appropriate and sustainable land-use systems (Nielsen and Zobisch, 2001 quoting Hare, 1985; Roe et al., 1998).

The current study is part of an ongoing land use planning programme in the study area called the 'Integrated Mission for Sustainable Development (IMSD)'. Databases on land use/cover, soils, terrain, geomorphology, groundwater prospects and infrastructure are generated at 1:50, 000 scale using remote sensing data and conventional surveys. These data are then integrated to generate 'action plans' for land and water management (NRSA, 1995, Nidumolu and Alanga, 2001, Harmsen and Nidumolu, 2002). The databases are intended for use by district level planning officials in the area of agricultural development and water and soil conservation in the wider perspective of district rural development. The IMSD study areas have been identified by the respective State and District Administrations as relatively less developed areas, experiencing resource- related problems such as land degradation, topsoil loss and sub-optimal yields. The selection of such areas for the study is supported by the views expressed by Ruben et al. (2003), who argue that a substantial impact on poverty alleviation and sustainable natural resources management might be expected from targeting investments in less-favoured areas (LFAs). The existing approach for generation of 'action plans' relies on generic prescriptions for the entire study area based on the resource potentials. However, we argue that land use analysis requirements vary for different areas in the region and stratification of the region for analysis will allow a focused attention on the specific requirements of an area. For example, if in an area rice is the predominant crop, the farmers in the area would benefit from advise on improved management practices for higher yields, while in another area, characterized by a multitude of crops, the farmers would benefit from advise on suitable crop selection. Alternatively, in areas where soil and water conservation is an issue, policy initiatives could support farmers in moving from agriculture to less demanding activities on the land such as for instance agro-forestry. Therefore, identifying these areas with different requirements as a precursor to a detailed land use analysis would make the analysis better targeted and more efficient. This argument is in tune with the idea of focusing efforts on development of Less Favoured Areas (LFA) as discussed by Hazell (2000).

In this paper, a method is described that uses the association between soils and broad land use classes to identify areas with specific agricultural land use analysis (LUA) objectives viz., Conservation, Crop Management Improvement and Crop Selection. Conservation is relevant in case of doubt about the suitability of the land for cropping and deals with the decision whether to crop the land at all. A mismatch between land quality and land use results in land degradation (Beinroth, 1994); this may be associated with strong negative impact of use on land quality and/or its productivity too low. In practice, large areas of such land are not cultivated or have been abandoned after cultivation. In case of Crop Management Improvement the focus is on optimising land use management without change in crops grown. The objectives of a Crop Management Improvement process include improving water and fertiliser use efficiencies through identifying limiting production factors and alleviating their impact through improved management. Crop Selection relates to choosing a suitable crop based on land suitability, market demands and in rain-fed areas reducing risks of investments and production while facing uncertain weather-specific yield-limiting conditions.

The objectives of this study are to stratify an area as a pre-field exercise for a focused land use analysis. To attain those objectives we: (a) identify relationships between soils and associated land cover/use and identify patterns in these relationships, (b) analyse the relationships observed on the basis of *a priori* knowledge of the area and the available statistics, and (c) verify these relationships in the field and through interviews with farmers. The results are intended for support of district land use planners in focusing on specific objectives in detailed land use policy formulation by district level land resources managers.

2. STUDY AREA

The study area is situated on the Deccan plateau in the western part of Nizamabad district of Andhra Pradesh state, India (Figure 1). According to soil taxonomy the soils in the study area can be classified into four major orders – Inceptisols (67%), Alfisols (15%), Vertisols (10%) and Entisols (8%). Geo-morphological features in the study area are of structural, denudational and fluvial origin. The study area is relatively flat with nearly 69% of the land in the 0-1% and 12% in the 1-3% slope category. The climate can be described as tropical, with an average annual rainfall of 897 mm received in 57 days, of which about 95% is received during the southwest monsoon. The climate is characterised by hot summers (maximum mean monthly about 40 ^{0}C) and generally cool and dry winters (minimum mean monthly about 13 ^{0}C).

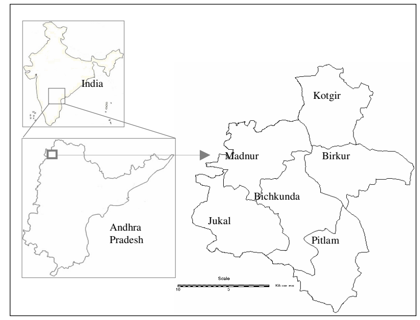


Figure 1: Location of Study area

Administratively, the study area comprises the mandals[1] Kotgir, Birkur, Bichkunda, Madnur, Jukal and Pitlam, with a total area of about 1300 km^2. It comprises 220 villages and a population of 294,000 (Census of India, 2001). Historically, agriculture is the primary occupation of the local population with about 80% depending on it for its livelihood. Total agricultural land is about 90,000 hectares and non-cultivated areas with or without scrubs about 18,000 hectares. Annual per capita income of the farmers is Indian rupees 33,000 (approx. US$ 700). The literacy rate is about 25%. Large numbers of farmers in the area are marginal to small farmers with holding sizes ranging from 0.5 ha to 3 ha. Population in the area increased from 222,000 in 1991 to 294,000 in 2001, an increase of about 3.2% per year (Chief Planning Officer, 1991, 2001). Statistical data from the same source also indicate a reduction of 20% in area of permanent pastures and an increase of 34% in agricultural area during the same period (Figure 2). These statistics indicate that the land resources in the area are under pressure, due to increased population pressure. Hence, the Deccan plateau of central India (of which the study area forms a part), consisting of fertile soils derived from basalt, where cultivation began many centuries ago and soil loss is expressed in meters rather than in millimeters, is a typical example of the worldwide problem of increasing pressure on land as a result of rising population (Hudson, 1987). This problem and its consequences for arable and pastoral production strategies and environmental degradation have been discussed extensively and fundamentally by for instance Boserup (1965) and Mortimore (1995). In line with Boserup's (op. cit.) reasoning Eswaran et al. (2001) state that high population density does not necessarily lead to

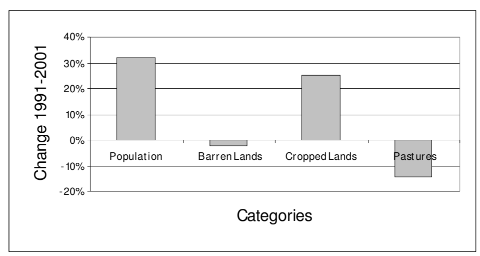


Figure 2: Land cover change area 1991-2001

[1] A mandal is an administrative sub-division of a district.

land degradation; it is what a population does to the land that determines the extent of degradation. People can be a major asset in reversing a trend towards degradation.

Two major agricultural seasons can be distinguished viz., Kharif (from June to October) and Rabi (November to March). About 33.8% of the study area is irrigated (including both the Kharif and Rabi seasons). Average rainfall in the rabi season is only 158.7 mm, therefore rabi crops are mostly grown where irrigation sources exist or in heavy black cotton soils that retain moisture from the monsoon rains. Crops such as jowar (*Sorghum bicolor* (L.) Moench) and bajra (*Pennisetum L. Rich*. (Poaceae)), with low water demands, are grown in these soils.

In heavy textured soils, sorghum is the principal crop, followed by cotton while other crops include safflower (*Carthamus*), bengal gram (*Cicer arietinum*) and dry chillies (*Capsicum annuum; C. frutescens*). Under assured irrigation on heavy textured clay loam soils, rice and sugarcane are the principal crops. Rice is cultivated in both the Kharif and Rabi seasons. On light textured soils (sandy loams and loamy sands), groundnut, sunflower, green gram and vegetables are the principal crops (Rao, 1995).

3. DATA

3.1 Map data

Land use maps depicting spatial cropping patterns were generated from Indian remote sensing satellite data for both, Kharif and Rabi of the same agricultural year. The maps were generated through visual interpretation techniques and use of topographic maps, district records and field investigations. Soil maps at scale 1:50,000 were generated within the IMSD project in India, up to *series* level, following the USDA approach for classification. Soils within a series are developed from the same parent material in the same environment and their profiles are almost alike with horizons that are similar in their properties (Dent and Young, 1981). The procedures adopted for generating the database are discussed in detail in the IMSD Technical Guidelines (NRSA, 1995). GIS data have been generated according to the National Natural Resources Information Systems (ISRO, 2000) standards.

3.2 Fieldwork Data

Fieldwork in the study area, consisting of field observations, interviews with farmers, and mandal and district line department officials, was conducted in two phases during May-July and September-December 2002. Digitizing/geo-referencing was facilitated through the use of a mobile GIS system; in the field, coordinates of the field interviews were recorded. Farmers' responses were defined as attribute data.

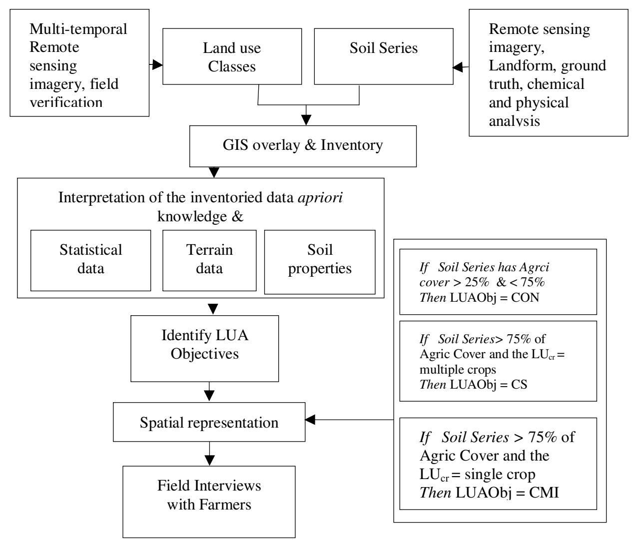
4. RESULTS

4.1 Analysis

The method is illustrated in Figure 3. Land use data were 'unioned' with soil data using standard GIS operations. The relationship between soil series and the overlaying land use was inventoried using the query facility in ArcView®, yielding data on areas of the major land use classes, Kharif-crops, Rabi-crops, (Kharif + Rabi)-crops, and non-cropped (divided into land with scrubs and land without scrubs) for each soil series.

Following the inventory of the relationships between soil series and the overlying land use classes, a method was developed to categorise the relationship as the basis for theoretical interpretations. The method is based on interpreting (i) percentage of cropped and non-cropped areas occurring in each of the soil series and their spatial distribution, (ii) data on spatial distribution of cropping pattern. The interpretation was to derive the land use analysis objectives for the study area. It is formulated as described below:

- Let S_i be the area of soil series (i = 1, 2….n).
- Let LU_{cr} be the area of major land use class cropped land (Kharif only, Rabi only and Kharif + Rabi, split in predominantly cropped to a single crop and cropped to many crops).
- Let LU_{ncr} be the area of major land use class non-cropped land (split in two cover classes, with and without scrubs).



LUA = Land Use Analysis; LUAObj = Land Use Analysis Objective; CMI = Crop Management Improvement; CS = Crop Selection; CON = Conservation; PRA = Participatory Rural Appraisal

Figure 3: Schematic presentation of the analysis method

Appraisal
Two groups of soil series have been distinguished, say A and B: Group A, those series in which agricultural land use exceeds 75% and Group B, series in which agricultural land use is less than 75%. The t-test to test if the two groups are statistically different reveals a value of 1.60 at *df* 17 which is significant at 95% confidence level, i.e. the two groups are significantly different.

® ArcView is a registered product of ESRI, Redlands, USA.

If in a soil series the land use classes Kharif, Rabi and Kharif + Rabi occupy seventy five percent or more of the area, the inference is that the local farmers consider the land as ‘suitable’ for agriculture. If a soil-series/sub-group is distributed evenly

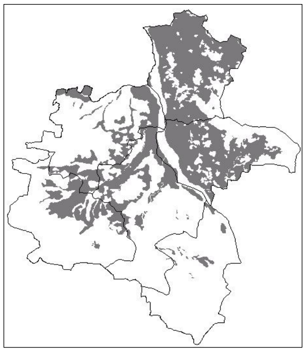


Figure 4A : Crop Management Improvement

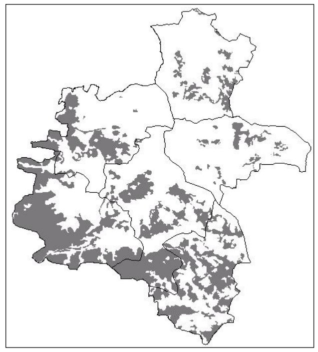


Figure 4B: Conservation

among agricultural and non-agricultural land use classes, that could be interpreted as either an indication of pressure on land (land less suitable for agriculture being used for agriculture) or of a limitation by (an)other constraint(s) (land suitable for agriculture, but not used). This interpretation forms the basis for identification of broad land use analysis objectives: Crop Management Improvement, Conservation, and Crop Selection.

Based on the above discussion, selection of the land use analysis objectives is formulated as (Table 3:A,B,C; Figure 4:A,B,C)):
If *soil series* S_1 is overlain by > 75% of LU_{cr} and predominantly a single crop, then the priority LUA objective is ”Crop Management Improvement (CMI)”. If *soil series* S_1 is overlain by > 75% of LU_{cr} in the area and multiple crops of cultivated, then the priority LUA objective is “Crop Selection (CS)”. If the *soil series* S_1 and LU_{cr} relationship is, 25% < *soil series* S_1 < 75%, then the priority LUA objective is “Conservation (CON)”, especially when the land has a poor cover (no scrubs). When Soil series S_1 overlain by < 25% LU_{cr}, then no priority is set with respect to LUA objectives.

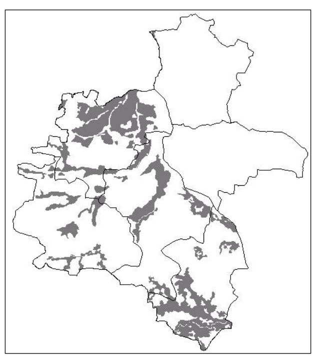


Figure 4C: Crop-Selection

4.2 Validation of results

The results from the foregoing analysis have been validated with reference to the following independent sources: (a) statistical data obtained from the District Planning Office, (b) Physical and chemical properties of the soils, (c) Terrain data in the form of a slope map, (d) Field visits and interviews with farmers.

a) Statistical data

Two sets of data available with the District Planning Office on extent of the irrigated area and areal extent of crops, aggregated to mandal level, have been used. Therefore, the areas covered by the three land use analysis objectives have been calculated at mandal level for comparison. The comparisons (Table 1) focus on the percent area covered by each of the land use analysis objectives in a mandal with (a) percent area under irrigation in the mandal and (b) percent area of a particular crop in the mandal. Percent areas have been used for ease of comparison. It can be seen from the Table 1, that Kotgir and Birkur mandals (where the *Bodhan, Anksapuram, Birkur* and *Uppalvai* series occur) have significant areas covered by CMI (85 and 87% of the mandal agricultural area, respectively).

Table 1: Extent of LUA Objectives (percent of total area) versus area (ha) devoted to major crops (percent area) in the study area

	CMI	CS	CON		Irrig area	Rice	Jowar	Pulses	Sugar cane	Ground nut	Cotton	Others
			Agric.	Non-agric								
Kotgir	85.00	0.50	8.60	5.90	42.8	42.35	8.50	9.40	16.00	2.15	9.30	12.30
Birkur	87.00	0.00	10.80	2.20	57	70.00	1.10	2.00	7.80	5.30	1.30	12.50
Bichkunda	33.80	26.00	23.60	16.60	28	16.80	20.20	22.80	3.50	2.30	18.0	16.40
Madnur	30.00	48.00	8.30	13.70	15	7.50	22.40	20.50	0.20	1.00	26.40	22.00
Jukal	21.00	34.00	14.50	30.50	2.5	2.10	28.00	27.50	0.10	0.30	22.70	19.30
Pitlam	4.40	49.00	37.80	18.90	7	37.45	15.90	21.25	6.25	7.45	5.20	6.50

The irrigated area in these mandals is 42.8% and 57%, respectively. Rice cultivation in these mandals covers respectively 42.35 and 70% of the agricultural area. Sugarcane is the next dominant crop with 16 and 7.2%. These data support the analysis that in areas characterized by a single dominant crop the main objective is improved crop management for higher yields. Alternatively, in Jukal mandal a

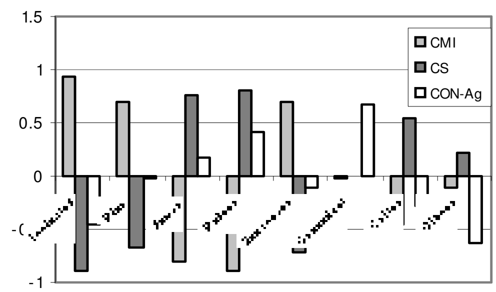


Figure 5: Correlations at mandal level between CMI, CS and CON areas and irrigated areas and crop types

higher percentage of the area is diagnosed for CS. It has a very small area under irrigation (2.5% of the agricultural area) and there is no dominant crop. Similar situations are found in other mandals, like Pitlam characterized by a significant area identified for CS. Here, in contrast to the areas identified for Crop Management Improvement (with predominantly rice cultivation), farmers grow a wide variety of crops. This is supported by data in Table 1, where crops such as jowar, pulses, sugarcane, groundnuts, cotton and others cover an average 78% of the agricultural area**.** These statistical data support the identification as CS areas, characterized by multiple cropping systems with restricted irrigation facilities. Farmers here could benefit from advice from the extension service on suitable crop selection. Note further that mandals with higher percentages of CMI areas are characterized by highly demanding crops, such as rice and sugarcane, while mandals with higher percentages of CS and CON areas are characterized by less-demanding crops, such as jowar and pulses. Figure 5 depicts the correlations at a mandal level between CMI, CS and CON areas and irrigated areas and crops types.

(b) Comparing the areas identified for CMI, CS and CON with terrain data

Areas identified for CMI and CS occur significantly (52.4 and 26.9%) in slope category 0-1%. This observation is in agreement with the idea that CMI- and CS-areas (basically identified for agriculture) should occur in flat land, while CON-Ag and CON-nonAg (identified for conservation) should occur in relatively more sloping land. A typical example of the latter is the *Chapta* series, showing visible signs of degradation, both on the remote sensing image and in our field investigations.

(c) Comparison with soil properties

Tables 3A,B,C show that within the areas identified for CON-Ag and CON-non_Ag the vast majority is characterized by very sandy soils (sand 80-88%), whereas areas identified for CMI and CS have lower sand contents and relatively deeper topsoils. Areas identified for CS are positively correlated with clay content. An example is Madnur mandal where 48% of the agricultural area is identified for CS, and 76% of the area has clay contents of 38-49.6%. These are basically areas of black cotton soils, exhibiting workability problems during the Kharif season. The farmers use these soils for agriculture during the post-monsoon period on residual soil moisture, with limited supplementary irrigation. A variety of crops are grown, viz., rice (7.5%), jowar (22.4%), pulses (20.5%), sugarcane (0.1%), groundnut (1.0), cotton (26.4%) and other crops (22%). These characteristics support the conclusion that farmers in such areas (identified as CS) could benefit from advice on suitable crop selection.

Tables 3A, B and C: Soil texture and depth of soil series in relation to the LUA Objectives

4A: CMI

Soil Series	Sand (%)	Clay (%)	Silt (%)	Depth (cm)
Bodhan	42	42	16	30
Anksapuram	50	35	15	14
Fateullapur	54	20	16	70
Birkur	45	35	20	15
Uppalvai	60	25	15	14

4B: CS

Soil Series	Sand (%)	Clay (%)	Silt (%)	Depth (cm)
Mardi	49	42	9	18
Maddalacheru	41	44	15	15
Waddarpalli	54	29	17	16
Chinnakodapgal	58	31	11	14
Masampalli	56	18	26	15
Peddakodapgal	33	50	17	15

4C: CON

Soil Series	Sand (%)	Clay (%)	Silt (%)	Depth (cm)
Bandapalli	80	11	9	15
Chapta	88	8	4	10
Pulkal-II	77	13	10	12
Sultanpet	86	7	7	14
Kottur	86	10	4	10
Bichkunda	82	12	6	15
Kaulas	87	12	5	16
Kallair	81	12	7	10
Yanglur	78	13	9	18

(d) Field visits and overview of farmers' responses

The field visits and interviews with farmers were conducted in eighteen villages across the six mandals of the study area (Figure 6). The procedure consisted of (i) identifying the CMI, CS and CON areas with the aid of a mobile GIS/GPS system and intervening farmers in the field. The questions related to farmers views on their soils, problems - as they perceived, suitability of their soils for crops, access to extension service, water availability. Based on our interviews with farmers, the purpose of which was to identify driving forces behind farmers' decisions on land use, and own field observations, we can conclude that some of the reasons for either degradation or sub-optimal use of land are: (i) presence of smallholder/subsistence farmers, (ii) insufficient water for irrigation, (iii) lack of or inadequate extension support, (iv) lack of funds to implement suggestions from the extension service and (v) specific dietary preferences for rice.

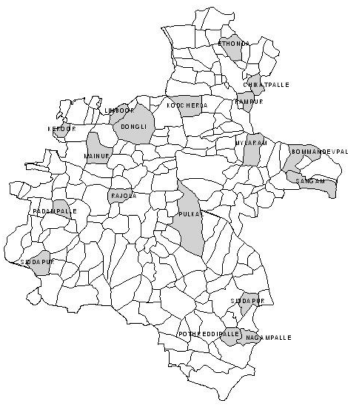


Figure 6: Field visit and interview locations with farmers

5. CONCLUSIONS

The results of this study show that different land use analysis objectives exist for different areas in the study area. The relationship between land (soil as an important land parameter) and land use can be used to differentiate such areas. These areas can be spatially depicted through application of GIS techniques. The results can be used to focus the efforts (when existing planning procedures are operational in an area) of planning and extension services in the area as follows: (a) Crop Management Improvement (CMI) areas are those that could benefit from improved management practices for higher yields. A detailed study of the management practices of farmers in the study area can help in identifying inadequacies in their current management and suggesting appropriate improvements. Methods, such as the Comparative Performance Analysis could be applied to identify yield gaps, in the present study this refers to rice cultivation. (b) Crop Selection (CS) areas are those that require advising farmers on suitable crop selection based on the constraints they face. Methods such as multiple goal optimisation techniques could be applied to generate cropping options, considering factors such as socio-economic conditions of the farmers, market opportunities and policy instruments and (c) Conservation areas present the most critical challenge to the resource managers. Questions as to why marginal lands are cultivated and why in some cases sub-optimal land use occurs have to be answered. The areas need specific alternatives in terms of a balance between land degradation and livelihoods of subsistence farmers. The resource managers need to identify alternatives to intense farming to prevent further degradation, while providing adequate livelihoods to local farmers. Advising farmers on alternatives for off-farm activities, silvo-pastural activities, agro-forestry, agro-horticulture and associated activities in combination with measures for soil and water conservation may be considered in the framework of integrated rural development schemes operational in the area. Although the method we developed focused on identification of land use analysis objectives, identification of the driving forces underlying farmers' decisions on land use will be useful in understanding the dynamics of land use in the study area.

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