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Agro-ecological zoning system - A remote sensing and GIS perspective

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ABSTRACT

Agro-ecological Zoning (AEZ) through remote sensing is an alternative to delineate areas having similar agro-climatic and agro-edaphic conditions for better assessing crop yield potentialities. This AEZ concept involves the representation of land in layers of spatial information and their combination using Geographical Information System (GIS). A GIS based model for agro-ecological zoning was developed and optimal land use is suggested for a watershed in Uttar Pradesh, India measuring 50 thousand hectares area

Satellite database on physiographic - soil, land use/land cover and digital elevation model (DEM) derived slope, along with agrometeorological parameters and ground water table information collected during field survey forms basic input. Ten agro-ecological zones and twenty three agro-ecological sub zones and their production potentials were identified. This zoning revealed that 27% and 14 % of the study area could be allocated for irrigated double cropping (sugarcane - wheat) and sole sugarcane cropping, respectively

Key words : Agro-ecological zoning, Remote sensing, GIS

Spatial referencing and managing resource data base are becoming increasingly important for sustainable agricultural development planning. Agricultural planning in past has not intensively dealt with the potentials and possible spatial extent of various levels of natural resource information (Pariyar and Singh, 1994). In recent times, GIS based Agro-Ecological Zoning (AEZ) system has emerged as versatile option, leading to an assessment of land suitability and yield potentialities of future crop combinations (FAO, 1996). This may help to identify the bio-climatic constraints limiting productivity to implement strategies for future food security.

Agro-ecological zoning (AEZ) refers to the division of an area of land into land resource mapping units, having unique combination of landform, soil and climatic characteristics and or land cover having a specific range of potentials and constraints for land use (FAO, 1996).

New tools for AEZ

Modern tools such as Satellite Remote Sensing and GIS have been providing newer dimensions to effectively monitor and manage natural resources such as agro-

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ecological zoning for sustainable development due to multi-stage character of the comprehensive approach. (Pratap *et al.*, 1998). GIS technology is very useful for automated logical integration of bio-climate, terrain and soil resource inventory information leading to Agro-ecological zoning.

Structure of AEZ

The structure of AEZ includes a comprehensive framework for the appraisal and planning of land resources (Fig. 1). The land resource data base is obtained by combining various data layers (map and tabular data) on the physical aspects of agricultural environments such as soils, landform and climate.

MATERIALS AND METHODS

Study area

The study area is Malin watershed in Kotdwar and Bijnor districts of Uttar Pradesh and lies between 29° 5' to 30° N latitude and 78° 5' to 78° 35' E longitude. It is elongated in shape having 48.32 km length and 14.31 km width, having an area of 50,967.33 hectare. It is bound on north by Garhwal district, on the east by Rampur and Nainital district and on the south by Moradabad, Muzaffarnagar and Meerut districts of UP.

Data base

Ancillary Data

Spring level : Tube well ID and its recent spring level along with location map.

Soil resource: Physiographic-soil map along with its characteristics

Collatoral : Survey of India Toposheets (1:50,000 scale).

Satellite data

Multi-sensor digital data of Indian Remote Sensing Satellite as given below were used. Dated 1998 and 1993 false

Satellite	Sensor	Data Type	Path & Row		Acquissition Date
IRS-1C	LISS III	FCC	97	50	March 2,99
IRS 1B	LISS II	FCC	97	50	Nov. 23,93

Meteorological data

Met Station	Data fields	Period (years)	Source
Lansdown	Rainfall Temp	10	District Forest Office, Lansdown
Kotdwar			District Forest Office, Lansdown
Nazibabad			Nazibabad Tehsil Office
Nagina			Res.Station, G. B. Pant University of Agriculture and Technology
Bijnor			District Magistrate Office

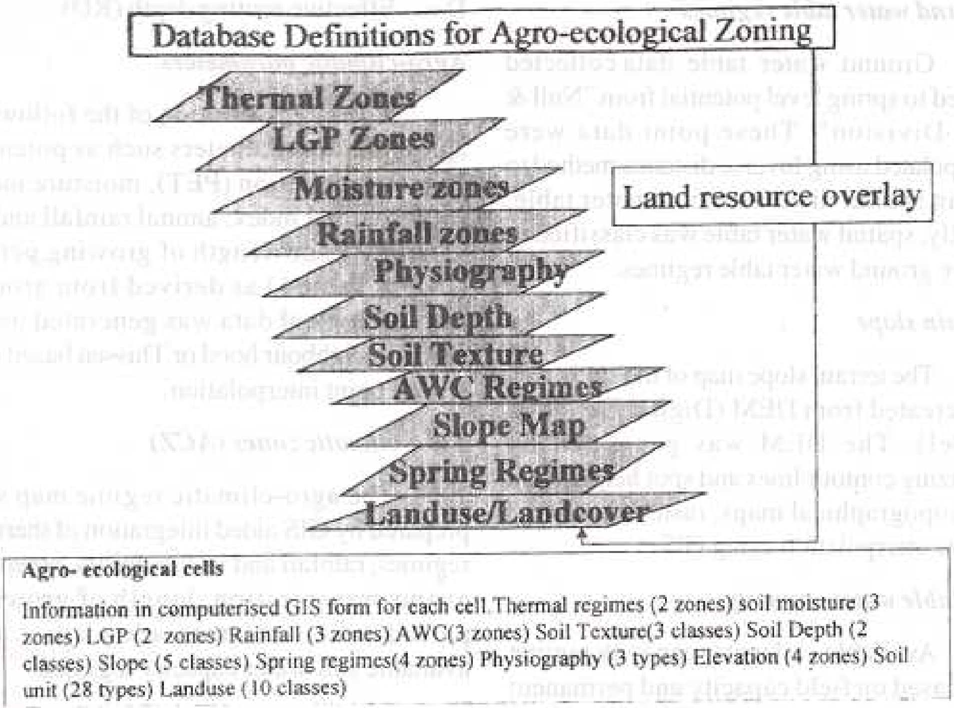

Fig. 1 : Structure of Malin Watershed land resource

colour composite (FCC) at 1:50,000 scale of the study area was used for ground truth data collection.

Preparation of natural resource data base

The primary thematic maps as prepared either using SOI map or satellite FCC were digitized and geo-processed using ILWIS (Integrated Land and Water information System) version 2.1 for creation of digital natural resources data base at 1: 50,000 scale.

Creation of physiographic-soil data base

The soil resource inventory was compiled from the report "Soil Resource Mapping and Evaluation Using Remote Sensing & GIS For Landuse Planning - A case study of Kotdwar Area (Prasad et al., 1999). The various steps followed in the generation of the data base were -

i) Identification of soil mapping unit characteristics

ii) Soil depth and texture were generated by GIS aided reclassification of digitized soil map using stored soil attribute data.

Similarly, physiography map of the study area was generated by GIS aided reclassification of digitized soil map.

Ground water table regimes

Ground water table data collected related to spring level potential from "Null & Kup Division". These point data were interpolated using Inverse distance method to obtain spatial distribution of water table. Finally, spatial water table was classified to derive ground water table regimes.

Terrain slope

The terrain slope map of the study area was created from DEM (Digital Elevation Model). The DEM was generated by digitizing contour lines and spot height from SOI topographical maps, rasterization and isoline interpolation using GIS.

Available water capacity

Available soil water capacity regime was based on field capacity and permanent wilting point of soil unit. It was calculated from soil water properties based on the following relations.

$U = [D \times F_1 \text{(texture)}] - F_2 \text{(stones)}$

Where,

U = available water capacity zone

F_1 = Function supplying the available water (as difference of field capacity FC and permanent wilting point (PWP) depending upon the textural class of physiographic soil unit.

F_2 = Reduction of available reserve by percentage of coarse material such as stones or gravel in each physiographic soil unit.

D = Effective rooting depth (RD)

Agro-climatic parameters

Spatial distribution of the following agroclimatic parameters such as potential evapotranspiration (PET), moisture index (MI), thermal index, annual rainfall and its variability and length of growing period (LGP) (Table 1) as derived from ground meteorological data was generated using nearest-neighbour hood or Thissen based met station point interpolation.

Agro-climatic zones (ACZ)

The agro-climatic regime map was prepared by GIS aided integration of thermal regimes, rainfall and its variability, potential evapo-transpiration, length of growing period zone, moisture adequacy and available soil-water capacity regimes.

Agro-edaphic zones (AEdZ)

For soil resources data base, three textural classes, viz. i) loamy skeletal indicating low suitability for all field crops, ii) coarse loamy indicating suitability for tuber and root crops, and iii) fine loamy indicating high suitability for all field crops were identified. Similarly two soil depth classes viz. i) Deep - depth more than 22.5 cm, indicating the soil suitability for agricultural use, and ii) Shallow - depth less than 22.5 cm, limiting the soil suitability to forestry and grazing (Carson, 1992) were considered. Similarly 5 slope classes were identified. Likewise, 4 ground water table regimes viz. Low, Medium, High and Very High were identified for agricultural use. Agro-edaphic zones were generated by GIS

Table 1 : Agro-climatic characteristics of weather station (1985-1994)

Station	Mean annual temp °C	Mean annual 1 rainfall (mm)	Mean annual PET(mm)	LGP days	Humid period (days)	Standard deviation of annual rainfall	Temporal rainfall (%)	Moisture Index Value
Nagina	21.92	885.0	1248.1	129	71	376.8	43	-29.09
Bijnor	22.79	1029.0	1248.1	119	74	329.0	32	-17.55
Nazibabad	24.70	1067.9	1474.6	123	76	230.0	22	-27.58
Kotdwar	21.88	1647.8	1253.5	160	95	357.1	22	31.46
Lansdown	21.72	1734.5	1149.5	151	110	362.4	21	50.89

aided integration of these parameters.

Agro-ecological zones (AEZ)

Finally, Agro-Ecological Zones and sub-zone maps was created by GIS aided integration of "agro - edaphic" and "agro-climatic" map layers. Agro-ecological cells were produced which were aggregated to define agro-ecological zones having similar land suitability and production potentialities of various cropping systems. Optimal suggested land use map was prepared by GIS aided integration of final AEZ and land use and land cover map layers. The flow chart is depicted in Fig.2.

Land potentiality

Storie Index (Storie, 1954) has been often used for land classification. Land potentiality was described by land productivity index as stated follows,

Land productivity index (LPI) = A* B* C*X*Y

Which are percentage rating for

A = general character of soil profile.

B = texture of horizon

C = slope of the land

X = site conditions (salinity, water table, drainage conditions)

Y= rainfall and temperature

RESULTS AND DISCUSSION

Delineation of agro-climatic zones

Five different climatic zones (ACZI to ACZ V) were delineated. Further thirteen agro-climatic zones were identified by GIS aided integration of 5 climatic zones and three available soil-water capacity (AWC) map layers. The spatial extent and characteristics of different agro-climatic zones are presented in Table 2. Thirteen different Agro-climatic Zones represent two thermal regimes viz. Warm, hot; two LGP zones viz. Semi arid (<50 days), sub-humid (>150 days); three rainfall zones viz. Annual rainfall 800-1000 mm, 1000-1250 mm, 1500-2000 mm with variability 42%, 22-32% and 21-22% respectively; four moisture regimes viz. 20-50, 50-100, 0-20 and -20 to -50 MI. Similarly Agro-climatic zones represent

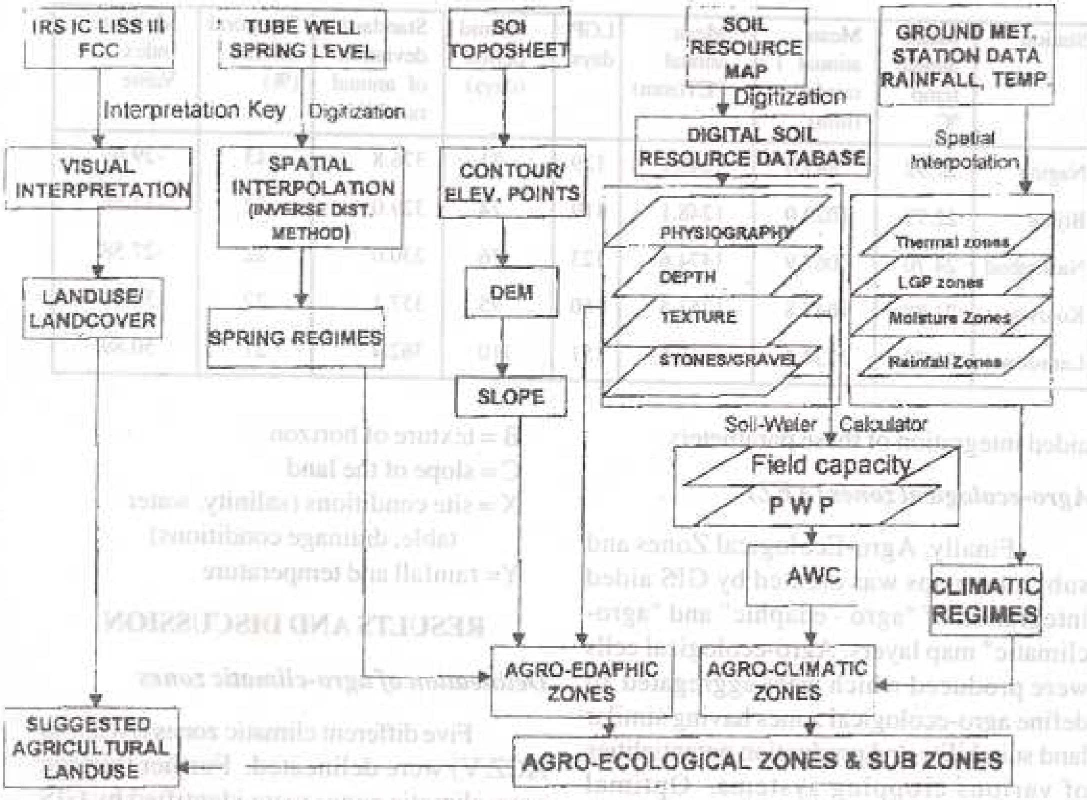

Fig. 2 : Flow chart methodology for agro-ecological zoning

three available soil water capacity regimes viz. Low (<100 mm/m depth), medium (100-150 mm) and high (>150 mm).

Delineation of agro-ecological zones and sub-zones

Twenty three Agro-Ecological Sub Zones (AEZ1a to AEZXb) were delineated in the study area by GIS aided integration of 13 Agro-Climatic and 29 Agro-edaphic Zones. Their spatial distribution and characteristics are presented in Table 3 and Figure 3, respectively. Table 3 indicates that area of sub-zones ranges from 0.22% to 24.34%. Majority of the area falls in IXb class whereas minimum area is occupied by IIIc. The other larger sub-zones are Ib and Va, IIb respectively. Agro-ecological sub zones are differentiated in terms of slope gradient, landforms and water table.

The sub-ecological zones are reclassified by GIS aided integration in which sub-zones are clubbed into main agro-ecological zones. Therefore, ten agro-ecological zones (AEZ1 to AEZX) are

Table 2 : Spatial extent & characteristics of agro-climatic zones

ACZ	Description	Area (ha) (%)	Area (ha)
ACZ 1a	Warm (<22°C), sub-humid, LGP (150-180 days), MAI wet (50-100 , RF 1500-2000 mm with 15-25% variability (15-25), low awc (< 100 mm/m depth)	3323.66	6.52
ACZ 1b	Warm (<22°C), sub-humid, LGP (150-180 days), MAI wet (50-100), RF 1500-2000 mm with 15-25% variability (15-25), medium awc (100 - 150 mm/m depth)	4483.28	8.80
ACZ 2a	Warm (<22°C), sub-humid, LGP (150-180 days) MAI moist (20 to 50), RF (1500-2000 mm) with 15-25% variability (15-25), low awc (<100 mm/m depth)	254.26	0.50
ACZ 2b	Warm (<22°C), sub-humid, LGP (150-180 days) MAI moist (20 + 50), RF (1500-2000 mm) with 15-25% variability, medium awc (100-150 mm/m depth)	7694.07	15.10
ACZ 2c	Warm (<22°C), sub-humid, LGP (150-180 days) MAI moist (20 to 50 , RF (1500-2000 mm) with 15-25% variability (15-25), high awc (>150 mm/m depth)	4425.12	8.69
ACZ 3b	Warm (<22°C), semi-arid , LGP (90-150 days) MAI slightly dry (0 to -20 mm), RF (1000-1250) with 20-35% variability, medium awc (100 - 150 mm/m depth)	1931.05	3.79
ACZ 3c	Warm (<22°C), semi-arid , LGP (90-150 days) MAI slightly dry (0 to 2- 0 mm), RF (1000-1250 mm) with 20-35% variability (20-35), medium awc (100 - 150 mm/m depth)	924.36	1.81
AEZ 4a	Hot, semi-arid (LGP 90-150 days), MAI dry (-20 to -50), RF (1000-1250) with 20-35% variability, low awc (<100 mm/m depth)	117.30	0.23
ACZ 4b	Hot, semi-arid (LGP 90-150 days), MAI dry (-20 to -50), RF (1000-1250) with 20-35% variability, low awc (<100 mm/m depth)	18433.88	36.18
ACZ 4c	Hot, semi-arid (LGP 90-150), MAI dry (-20 to -50), RF (1000-1250) with 20-35% variability, low awc (<100 mm/m depth)	1887.81	3.71
ACZ 5a	Warm (<22°C), semi-arid (90-150 days), semi-dry, MAI (-20 to -50), RF (800-1000 mm) with 30-50% variability (30-50), low awc (<100 mm/m depth)	68.42	0.13
ACZ 5b	Warm (<22°C), semi-arid (90-150 days), semi-dry, MAI (-20 to -50), RF (800-1000 mm) with 30-50% variability (30-50), medium awc (100- 150 mm/m depth)	3997.24	7.85
ACZ 5c	Warm (<22°C), semi-arid (90-150 days), semi-dry, MAI (-20 to -50), RF (800-1000 mm) with 30-50% variability (30-50), high awc (>150 mm/m depth)	1379.63	2.71
River		1705.73	3.35
Town		320.36	0.63
Total		50938.66	100.00

Table 3 : Spatial extent & characteristics of agro-ecological sub zones

AEZ	AEZ SUB	DESCRIPTION	AREA (ha)	(%)	Land Productivity Index (%)	* Major suggested land use
I	a	Undulating Hills, deep loamy skeletal soils and low-medium water tables, warm sub-humid LGP (150-180 days); RF (1500-2000 mm), (low-medium AWC)	468.6	0.92	17.3	Rainfed cropping (Millets/wheat)
	b	Mod. To steep sloping hills with deep Loamy skeletal soil, low-medium water table, warm sub-humid LGP (150-180 days) RF (1500-2000 mm) with low-medium AWC	6920.8	13.6	25.93	Terrace cultivation(Wheat)/ Pasture development
	c	Mod. To steep sloping hills with shallow loamy skeletal soil, low water table, warm sub-humid LGP (150-180 days), RF (1500-2000 mm) and low AWC	888.6	1.74	25.58	Terrace cultivation(Wheat)/ Pasture development
II	a	Nearly level piedmont, deep fine loamy soils, with high water table, warm sub-humid, LGP (150-180 days), RF (1500-2000 mm) with medium - high AWC.	465.1	0.91	65.79	Intensive cropping (Sugarcane/wheat)
	b	Nearly level piedmont, deep fine loamy soils, with low to medium water table, warm sub-humid, LGP (150-180 days), RF (1500-2000 mm) with medium - high AWC.	2823.7	5.54	62.8	Intensive cropping (Sugarcane/wheat)
	c	Gently sloping piedmont plain with deep fine loamy soils with low to medium water table, warm sub-humid LGP (150-180 days), RF (1500-2000 mm) with medium to high AWC	682.0	1.34	58.8	Intensive cropping (Sugarcane/wheat)
	d	Gently sloping piedmont plain with deep fine loamy soils with low to medium water table, warm sub-humid LGP (150-180 days), RF (1500-2000 mm) with low to medium AWC	3094.5	6.08	55.4	Rainfed cropping (Paddy - wheat)
III	a	Nearly level,, piedmont plain, deep fine loamy soils, high to very high water table, hot semi-arid; LGP (90-150 days) RF (1000-1250 mm) with medium to high AWC.	1947.6	3.82	62.5	Sole cropping (sugarcane)
	b	Nearly level piedmont plain, deep fine loamy soil and high to very high water table, warm, semi arid; LGP (90-150 days), RF (800-1000 mm) with medium to high AWC	370.0	0.73	68.3	Irrigated cropping (Paddy - wheat)
	c	Gently sloping piedmont plain, deep fine loamy soils and high water table, hot semi arid:(LGP (90-150 days), RF (1500-2000 mm)) with high medium to high AWC.	110.6	0.22	55.7	Sole cropping (sugarcane)
IV	a	Nearly level piedmont plain with coarse loamy soils and low to medium water table, warm sub-humid (LGP (150-180 days) RF (1500-2000 mm)) with medium to high AWC.	1017.1	2.00	72.5	Intensive cropping (Sugarcane/Wheat)
	b	Gently sloping piedmont plain with coarse loamy soils and low to	2275.9	4.47	70.3	Sole cropping

Table 3 : Contd...

		medium water table warm sub-humid; LGP (150-180 days), RF (1500-2000 mm)) with medium to high AWC.				(Sugarcane)
	c	Gently sloping piedmont plain with loamy skeletal soils, low water table, warm, sub-humid; LGP (150-180 days) RF (1500-2000 mm)) with medium AWC.	1286.2	2.52	38.5	Rainfed cropping (Millets/Wheat)
V	a	Nearly level piedmont plain with coarse loamy soil and high - very high water table, hot - semi - arid; LGP (90-150 days) RF (1000-1250 mm)) with medium to high AWC.	5809.6	11.4	53.8	Sole cropping (Sugarcane)
	b	Gently sloping piedmont plain with coarse loamy soils and high water table, hot, semi - arid; LGP (90-150 days) RF (1000-125- mm)) with medium to high AWC.	2037.2	4.0	56.4	Sole cropping (Sugarcane)
VI	a	Undulating piedmont plain, deep loamy skeletal soil and low water table, warm sub humid; LGP (150-180 days) RF (1500-2000 mm) and low to medium AWC.	122.5	0.24	29.8	Rainfed cropping (Millets/Wheat)
	b	Mod. To steep sloping piedmont lain with deep loamy skeletal soil and low water table, warm, sub humid; LGP (150-180 days), RF (1500-2000 mm)) and low AWC	91.7	0.18	32.5	Rainfed cropping (Millets/Wheat)
VII	a	Nearly level piedmont plain with coarse loamy soils and high water table, warm, semi arid; LGP 90-150 days) RF (800-1000 mm) with medium to high AWC.	402.7	0.79	71.6	Intensive cropping (Sugarcane/Wheat)
VIII	a	Nearly level alluvial plain with deep fine loamy soils and high to very high water table, warm, semi-arid; LGP (90-150 days), RF (1000-1250 mm)) with medium AWC	312.6	0.61	78.9	Irrigated double cropping (sugarcane - wheat)
IX	a	Nearly level alluvial plain, deep coarse loamy soils and high ground water table, hot semi-arid; LGP (90-150 days) RF (1000-1250 mm) with high AWC	2417.7	4.75	76.2	Irrigated double cropping (Sugarcane - Wheat)
	b	Nearly level alluvial plain, deep coarse loamy soils and high water table, warm, semi arid; LGP (90-150 days), RF (800-1250 mm) with low to medium AWC.	12397.5	24.3	82.3	Irrigated double cropping (Sugarcane - Wheat)
X	a	Nearly level alluvial plain, deep coarse loamy soils and very high water table, hot, semi-arid; LGP (90-150 days), RF (1000-1250 mm) with high AWC.	1044.7	2.05	90.1	Multiple cropping (Sugarcane/vegetable - Wheat)
	b	Nearly level alluvial plain, deep coarse loamy soils and very high water table, warm, semi-arid; LGP (90-150 days), RF (800-1250 mm) with low to medium AWC.	1925.9	3.78	86.3	Multiple cropping (Sugarcane/vegetable - Wheat)
	Town River		320.4 1705.4 50938.66	0.63 3.5 100		

* = Suggested agricultural land use for only arable land (except forested areas)

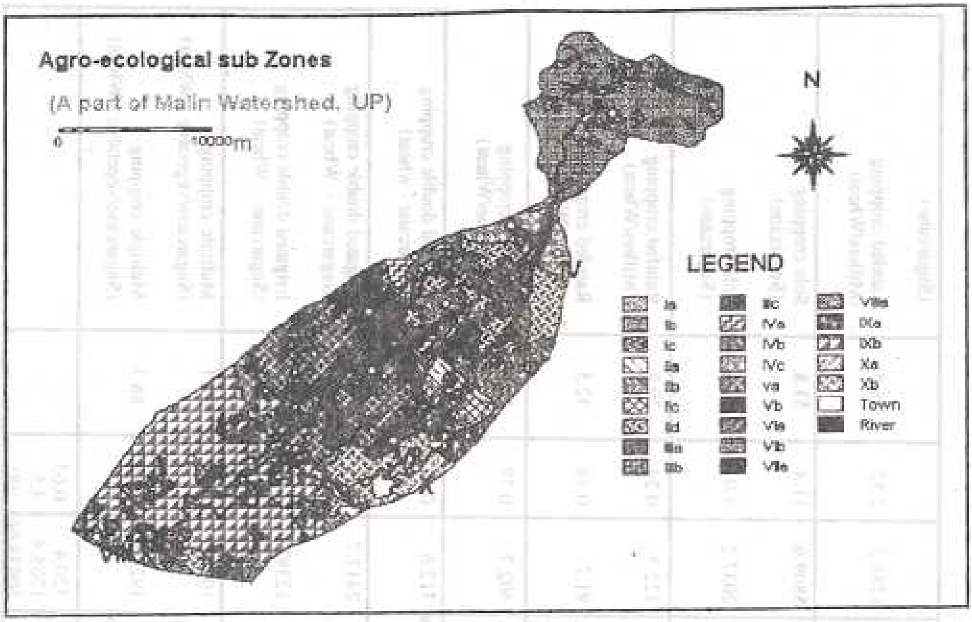

Fig. 3 : Agro-ecological sub zone map

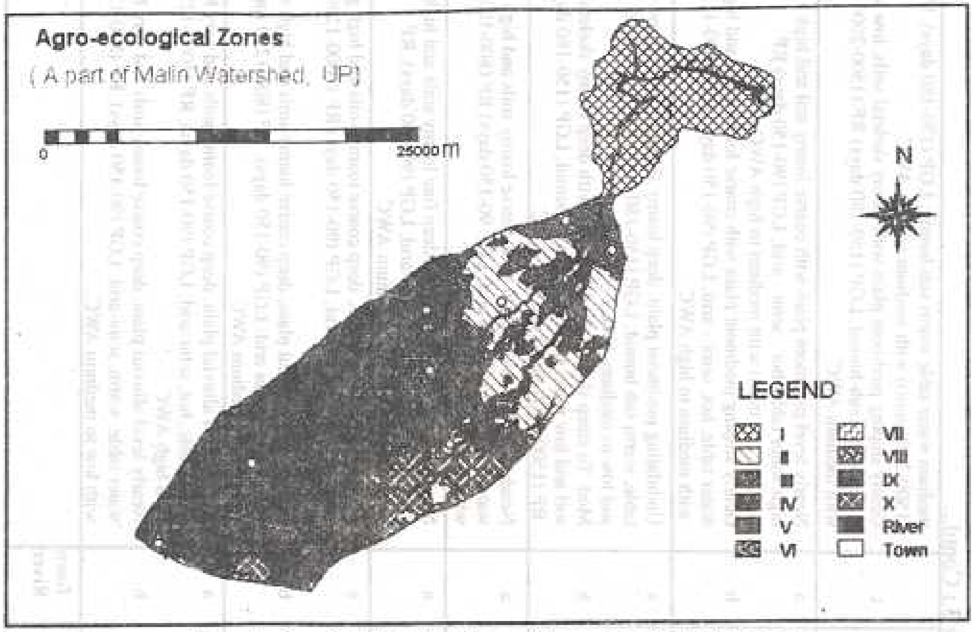

Fig. 4 : Spatial distribution of Agro-ecological zone

Table 4 : Spatial extent & characteristics of agro-ecological zones

AEZ	Description	Area (ha)	Area (%)
I	Warm, sub-humid hills with loamy skeletal soils.	8278.06	16.25
II	Warm, sub-humid, piedmont plain with fine loamy soils.	7037.05	13.81
III	Hot, semi-arid piedmont plain with deep fine loamy soils.	2428.19	4.77
IV	Warm, sub-humid piedmont plain with coarse loamy soils.	4579.20	8.99
V	Hot, semi-arid piedmont plain with coarse loamy soils	7846.81	15.40
VI	Warm, sub-humid piedmont plain with loamy skeletal soils.	214.22	0.42
VII	Warm, semi-arid piedmont plain with coarse loamy soils.	402.70	0.79
VIII	Warm, semi-arid alluvial plain with fine loamy soils.	312.63	0.61
IX	Semi-arid alluvial plain with coarse loamy soils, high ground water table.	14793.12	29.04
X	Semi arid alluvial plain with coarse loamy soils and very high ground water table.	3020.59	5.93
Town		320.36	0.63
River		1705.73	3.35
Total		50938.66	99.99

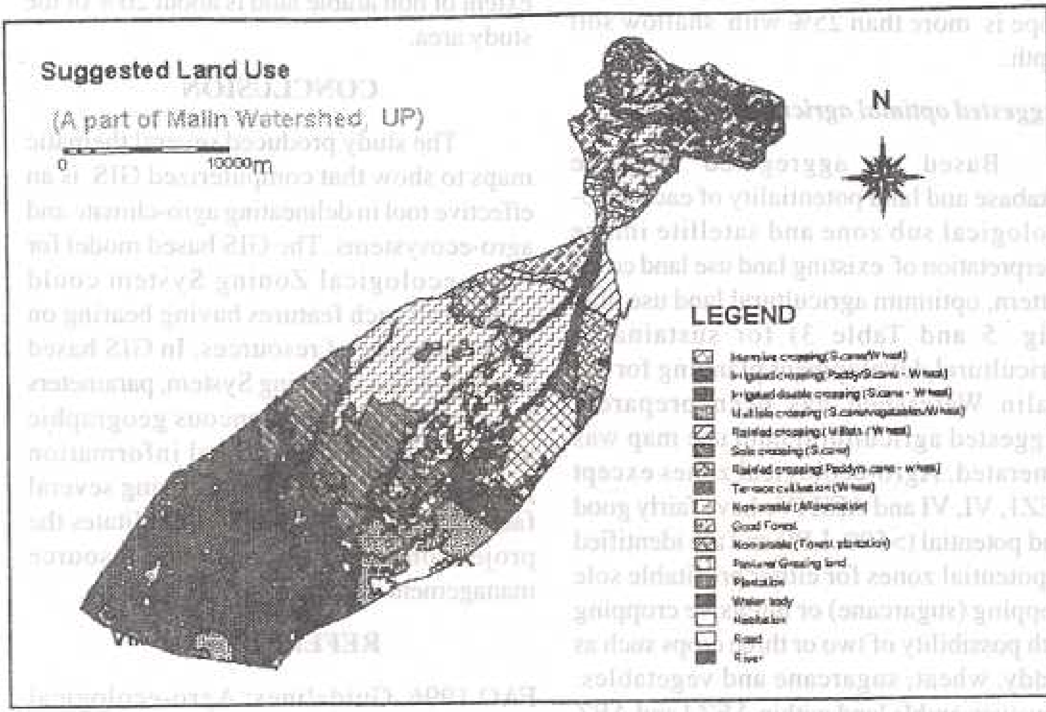

Fig. 5 : Suggesred optimal agricultural land use

identified in the study area. The spatial distribution and overall characteristics are presented in Table 4 and Figure 4 respectively. There is spatial distribution variation in AEZ. The area covered ranges from 0.42% in AEZ VI to 29.04% in AEZ IX. The whole hilly portion falls in AEZ I whereas lower alluvial plain is included in AEZ IX.

The AEZ II to X are identified as arable zones with decreasing level of potential for agricultural development. Shallow soil depth (<22.5 cm) is limiting its suitability for forestry and pasture. It is not suited arable agriculture. The terrain slope <25% is the upper limit of arable agriculture. AEZ 1 is not arable zone because terrain slope is more than 25% with shallow soil depth..

Suggested optimal agricultural landuse

Based on aggregated resource database and land potentiality of each agro-ecological sub zone and satellite image interpretation of existing land use land cover pattern, optimum agricultural land use plan (Fig. 5 and Table 3) for sustainable agricultural development planning for the Malin Watershed has been prepared. Suggested agricultural land use map was generated. Agro-ecological zones except AEZ1, VI, VI and AEZ IVc have fairly good land potential (>50% LPI) and are identified as potential zones for either profitable sole cropping (sugarcane) or intensive cropping with possibility of two or three crops such as paddy, wheat, sugarcane and vegetables. However, arable land within AEZ I and AEZ VI could be allocated to terrace cultivation/ pasture development and rainfed cropping (millets/wheat). These zones have very low land potential (<40% LPI) due to topography and soil depth limitations. It was also noticed that AEZ IX and AEZ X have very good potentiality (>75% LPI) and irrigation infrastructure. These are suitable for highly remunerative farming system i.e. irrigated double cropping (sugarcane - wheat) and multiple cropping (sugarcane/vegetable - wheat). Depending upon present land use/ land cover details, it was found that majority of area in AEZ I and AEZ V are under forest with dense canopy cover. Hence, these zones should be specifically brought under protection from biotic pressure. The areal extent of non arable land is about 26% of the study area.

CONCLUSION

The study produced several thematic maps to show that computerized GIS is an effective tool in delineating agro-climate and agro-ecosystems. The GIS based model for Agro-ecological Zoning System could capture all such features having bearing on the harnessing of resources. In GIS based Agro-ecological Zoning System, parameters for classifying homogeneous geographic units (Zones) and the zonal information profiles can be developed by using several factors. Even within zones, it facilitates the projection of development and resource management imperatives for each zone.

REFERENCES

FAO 1996. Guidelines: Agro-ecological zoning; Soils Bulletin. Rome, FAO.

Prasad, J, Suresh Kumar, Pande, L.M., Subramanyam, C., Patel, N.R. and Saha, S.K. 1999. Soil resource mapping and evaluation using remote sensing and GIS for land use planning - A case study of Kotdwar area. Proceeding of National Symposium on Remote Sensing Emphasis on Infrastructure development held at NRSA, Hyderabad, pp. 169 - 175.

Pratap, T., Pradhan, P., Lotta, P.K., Mya, S., Karim, Z. and Nakarmi, G. 1998. Sustainable Mountain Agriculture, MENRIS Division, ICIMOD, Nepal.

Pariyar, M.P. and Singh, G. 1994. GIS based model for agro-ecological zoning: a case study of Chitwan district, Nepal. Proceedings of 15th Asian Conference Remote Sensing, Bangalore, India. Vol. 1 : A4-1 to A4-6.

Storie, R. E. 1954. Land classification as used in California. Proceedings 5th International Congress Soil Science, Leopoldville, 3:407 - 412.