REMOTE SENSING AND GIS APPLICATION IN AGRO-ECOLOGICAL ZONING

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Abstract : Sustainable agricultural development requires a systematic effort towards the planning of land use activities in the most appropriate way, apart from several other institutional and policy programme initiatives. Agro-ecological zoning (AEZ) is one of the most important approaches for agricultural developmental planning because survival and failure of particular land use or farming system in a given region heavily relies on careful assessment of agro-climatic resources. This approach is used to categorize agro-climatically uniform geographical areas for agricultural developmental planning and other interventions. Modern tools such as satellite remote sensing and Geographical Information System (GIS) have been providing newer dimensions to effectively monitor and manage land resources in an integrated manner for agro-ecological characterization. The application of AEZ is limited by lack of geospatial data, particularly in mountainous areas. This paper tries to demonstrate incorporation of new tools to extend applicability of AEZ in mountainous areas like Kumaon Himalayas, India.

INTRODUCTION

Sustainable agricultural development requires a systematic effort towards the planning of land use activities in the most appropriate way, apart from several other institutional and policy programmme initiatives. Agro-ecological zoning (AEZ) is one of the most important bases for agricultural developmental planning because survival and failure of particular land use or farming system in a given region heavily relies on careful assessment of agro-climatic resources. A practical zoning approach thus arises because climate represented by thermal and moisture regimes forms small geographic areas, resulting in a variable mosaic of specialized areas, capable of supporting varied land use systems (Troll, 1965). The approach is used to categorize agroclimatically uniform

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geographical areas for agricultural developmental planning and other interventions. A framework of agro-ecological zoning describing concepts, methods and procedures was conceptualized for the first time by FAO (1976). Agro-ecological zoning 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). The particular parameters used in the definition focus attention on the climatic and edaphic requirements of crop and on the management systems under which the crops are grown. Each zone has a similar combination of constraints and potentials for land use and serves as a focus for the targeting of recommendations designed to improve the existing land use situation, either through increasing production or by limiting land degradation. The addition of further layers of information on such factors as land tenure, land availability, nutritional requirement of human and livestock populations, infrastructure and costs and prices, has enabled the development of more advanced applications in natural resource analysis and land use planning. AEZ can be regarded as a set of core applications, leading to an assessment of land suitability and potential productivity. An output of AEZ studies includes maps showing agro-ecological zones and land suitability, quantitative estimates on potential crop yields and production. Such information provides the basis for advanced applications such as land degradation assessment, livestock productivity modeling, population support capacity assessment and land use optimization modeling.

IMPORTANCE OF AEZ IN SUSTAINABLE AGRICULTURAL DEVELOPMENT PLANNING

The ability of the world's natural resources to provide for the needs of its growing population is a fundamental issue for the international community. World's population is increasing rapidly and at the same time, essential natural resources, such as land and water, are declining both in quantity and quality due to such factors as competition with industrial and urban demands. The basic problem is that limits to the productive capacity of land resources are set by climate, soil and land forms condition. In this context AEZ can be regarded as a set of applications, leading to an assessment of land suitability and potential productivity in terms of climate, soil and land forms condition.

Agro-Ecological Zoning (AEZ) is one of the most important bases of sustainable agricultural development planning of a region. It is applicable in micro or local level planning mainly for rainfed agriculture. It assesses basically the yield potentialities of various crop conditions; evolves future plan of action involving crop diversification; determines suitability of different crops for optimizing land use, disseminates research results and agro-technology. As a result sustainable agricultural development planning is increasingly being based on agro-ecological zones. In this process agro climate zoning has become very popular (Verma and Partap, 1989). The initial focus of the FAO agro-ecological zoning system was to assess the suitability of different types of land use for selected land uses. It is an important starting point for selected land use planning with an overview of the whole region. It diagnoses the present situation with regard to farming and land use by categorizing, describing and analyzing, farming systems components.

DEFINITIONS

Agro-Ecological Zoning (AEZ) refers to the division of an area of land into smaller units, which have similar characteristics related to land suitability potential production and environmental impact.

Agro-Ecological Zone is a land resource mapping unit, having a unique combination of land form, soil and climatic characteristics and/or land cover having a specific range of potentials and constraints for land use (FAO, 1996).

Agro-Ecological Cell (AEC) is defined by a unique combination of land form, soil and climatic characteristics

TRADITIONAL APPROACH

Several attempts have been made to classify the land area into climatic regions. Many of the earlier efforts to delineate agro-climates used manual overlay of isolines representing either potential evapotranspiration or temperature or their combinations and superimposed on soil resource maps. Carter (1954) divided India into six climatic regions, ranging from arid to per humid, based on the criteria of Thornthwaite system of climate classification. Sehgal *et al.* (1987) prepared a computerized bio-climatic map of NW India, based on the criteria of dry month. Krishnan (1988) delineated 40 soil climatic zones based on major soil types and moisture index. Murthy and Pandey (1978) brought out a 8 agro-ecological region map of India on the basis of physiography, climate, soils and agricultural regions. The approach depicts a good beginning of agro-ecological zoning in the country, but it suffers from several limitations due to over generalizations such as grouping together the areas having different physiography, temperature and soil in zone.

Subramanian (1983) based on the data of 160 meteorological stations in the country and using the concept of moisture adequacy index, delineated 29 agro-ecological zones with the possible 36 combinations of IMA and dominated soil groups as per FAO/UNESCO Soil Map (1974).The planning commission, as a result of mid-term appraisal of the planning targets of VII Plan (1985-1990), divided the country into 15 broad agro-climatic zones based on physiography and climate (Sehgal *et al*., 1992).

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. It has been well conceived that remote sensing and GIS have great role to play in agro-ecological zoning for sustainable development due to multi-stage character of the comprehensive approach to agro-ecological zoning (Pratap *et al*., 1992). Several approaches of AEZ in past involved manual integration of agro-climatic and other natural resource data (Mavi, 1984; Venkateswaralu *et al*., 1996). As a result, large amount of agro-ecological data could not be handled easily and aggregation was required at an early stage in the analysis. This led to loss of information on spatial variability. On the other hand, GIS technology is very useful for automated logical integration of bio-climate, terrain and soil resource inventory information (Patel *et al*., 2000). The system is capable of containing all data required to solve resource management problems. Topographic maps, land resource map and contour map having physiographic, geographic and bio-climatic information forms primary input for GIS for agro-ecological zoning activities. The system also facilitates the enlargement of a particular geographic pocket to render more details on retrieval. After collecting the basic data on zonal resource information, the data can be manipulated to create relevant profiles of applied use that can be retrieved on demand. A zonal database can also be integrated with non-geographic information such as socioeconomic data, which is relevant for making decision on development priority interventions about the sustainable management of zonal resources. Remote sensing provides digital or hard copy data base information on natural resources. This information can be stored and retrieved as and when required and also data can be classified and aggregated for any number of planning exercises. This AEZ concept involves the representation of land in layers of spatial information and combination of layers of spatial information using geographic information system (GIS).

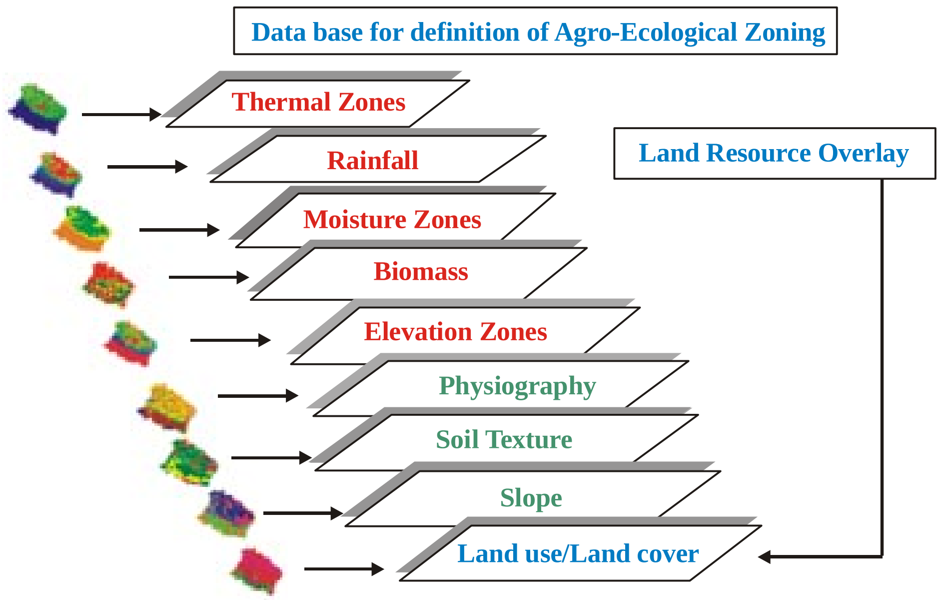
STRUCTURE OF AEZ

The structure of AEZ includes the comprehensive framework for the appraisal and planning of land resources (Figure 1). The nature of analysis, which involves the combination of layers of spatial information to define zones, lends itself to application of a GIS. The major requirements of computerized GIS for an activity like agro-ecological zoning and zonal resource information of mountain areas are topographic maps, land resource maps and contour maps. These maps, containing physiographic, geographic, and bio-climatic information form primary inputs. Various outputs are generated in both tabular and map forms. Till date, good progress has been made in developing GIS based tools for land resources planning, management and monitoring at different scales.

ELEMENTS OF AEZ

The essential elements of the core applications of AEZ include :

- ❑ Land resource inventory, comprising
  - Analysis of length of growing period or moisture availability index
  - Defining thermal zones
  - Compilation of climatic resource inventory
  - Compilation of soil and landform resource inventory
  - Compilation of present land use inventory
  - Combination of above to make land resource inventory based on agro-ecological zones or agro-ecological cells.
- ❑ Inventory of land utilization types and crop requirements
- ❑ Land suitability evaluation, including
  - Potential productivity computations
  - Matching of constraints and requirements



Agro-ecological cells

Information in computerised GIS form for each cell. Thermal regimes (3 zones) soil moisture (8zones) Rainfall (5 zones) Soil Texture (3 classess) Slope (4 classes) Physiography (3 types) Elevation (5 zones) Soil unit (47 types) Landuse (10 classes)

Figure 1: Structure of land resource

A CASE STUDY ON AGRO-ECOLOGICAL ZONING IN MOUNTAIN ECOSYSTEM

Sustainable development of mountain regions is a challenging task because the areas have highly diverse and fragile ecosystems. One of the most striking characteristics of mountains is their spatial variability. This makes the planning of the use of natural resources in the mountains more complex than any other area. In view of this, the present study was conducted in part of Kumaon Himalayas (latitudes 28°45’ to 30°00’N, longitude 78°45’ to 80°15’) to demonstrate the use of remote sensing and GIS as a tools for agro-ecological zoning with mountain perspective (Patel *et al.*, 2002). The methodology used in this study is outlined in the flow diagram in Figure 2. This methodology is further described as following sub heads.

Climate

Long term (approximately 10 years) monthly maximum and minimum temperatures were collected from six meteorological stations falling in the

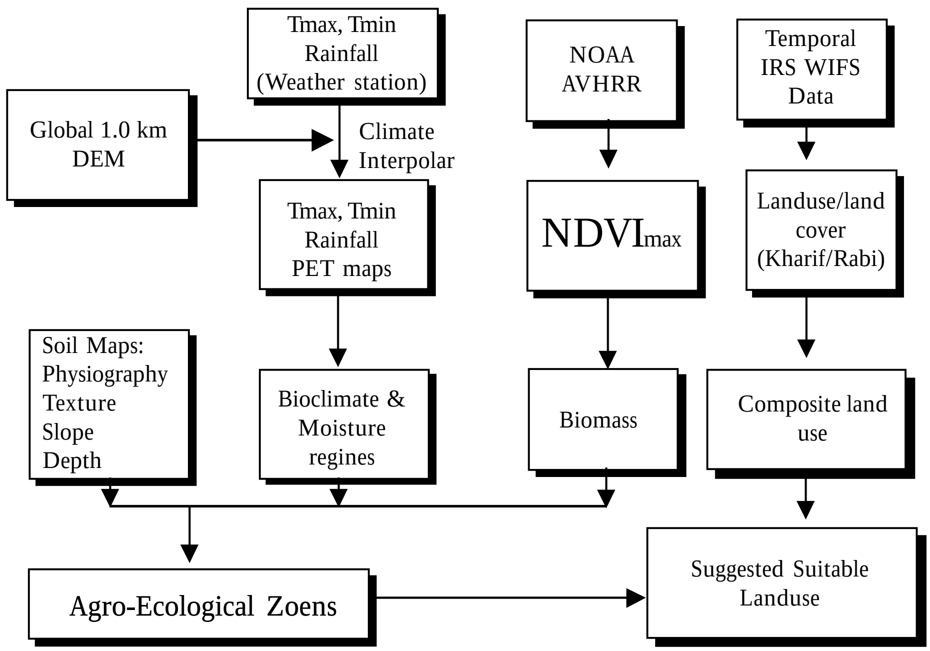


Figure 2 : Flow diagram of the method for agro-ecological zoning

western Himalayas. However, monthly rainfall data for eight years were collected from eleven rain gauge stations within the study area. The details about location of meteorological and rain gauge stations are shown in Table 1. Digital elevation data with one-kilometer grid size was taken from Global Digital Elevation Model (USGS GDEM) and geometrically registered in UTM projection. Validation and accuracy check for digital elevation data derived from Global DEM was done with spot height observation from Survey of India toposheets on 1:250000 scale. A close agreement was observed between spot height observations and Global DEM based elevation data (R^2 = 0.98). Long term monthly and annual averages of mean temperatures of six meteorological stations were regressed against corresponding elevation using MICROSTA statistical software (Table 2). A good agreement was also observed between annual mean temperature and elevation (annual mean temperature = 24.443 - 0.0045 × elevation, R^2 = 0.97). Similarly long term average annual rainfall recorded at different rain gauge stations were regressed against elevation for developing rainfall – elevation relationship (annual rainfall = 515.1 + 0.3843 × elevation, R^2 = 0.75) representing the region under study. The empirical relations thus developed were used to utilize inherent spatial quality of digital elevation model in GIS environment for depicting spatial variation in normal monthly and annual mean temperatures as well as annual rainfall condition over Kumaon region. These monthly spatial distribution of mean temperatures were used for computation of spatial potential evapotranspiration (PET) based on Thornthwaite (1948) as:

$$PET = 1.6 \; [\; (10 \; T_{ijk}/I_{jk})^{ajk} \;]$$

where,

$$I_{jk} = \sum_{i=Jan}^{Dec} (T_{ijk}/5)^{1.514}$$

T = Mean air temperature (°C)

i = Month of a year (i = Jan, Feb, ……Dec)

j = Pixel value of i th row

k = Pixel value of j th column

$ajk = 67.5*10^{-8}(I_{jk})^3 - 7.71*10^{-5}*(I_{jk})^2 + 0.01792(I_{jk}) + 0.4923$

These monthly potential evapotranspiration were summed over twelve months in a year to obtain spatial distribution of annual PET for use in computation of moisture index (MI). The moisture index with positive and negative values indicates moist or dry climate and seasonal variation of effective moisture. The revised moisture index of Thornwaite and Mather (1955) method based on annual rainfall and potential evapotranspiration was calculated as,

$$MI = [(P - PET)/PET] * 100$$

where,

MI = Moisture Index

P = Rainfall (mm)

PET = Potential Evapotranspiration (mm)

This information on moisture index is vital to congenial biotic environment and has been used to classify the climatic types. To arrive at homogeneous zones, the limit of moisture index of the various climatic types was scaled as shown in Table 3.

Table 1. Data for fields and location of meteorological and rain gauge stations

No.	Met/rain gauge station	Data fields Monthly	Period (years)	- Latitude - Longitude	Elevation (meter)	Source
1.	Mukteswar	Rainfall, Temperature	10	29° 27' 28.7" N 79° 39' 27.2" E	2275	Institute Temperate Horticulture Station
2.	Hawalbagh	Rainfall, Temperature	10	29° 36' 00.0" N 79° 40' 00.0" E	1250	Met. Station
3.	Almora	Rainfall, Temperature	10	29° 35' 22.4" N 79° 38' 42.2" E	1528	Vivekanand ICAR Institute
4.	Pantnagar	Rainfall, Temperature	10	29° 02' 27.2" N 79° 24' 30.5" E	232	Agriculture University, Pantnagar
5.	Nainital	Rainfall, Temperature	10	29° 21' 30.7" N 79° 27' 26.3" E	1945	Astronomy State Observatory, Nainital
6.	Dehra Dun	Rainfall,Temperature	10	30° 19' 00.0" N 78° 02' 00.0" E	682	Met. Station
7.	Mussoorie	Rainfall, Temperature	10	30° 27' 00.0" N 78° 05' 00.0" E	2024	Met. Station, CSWCRII Dehra Dun
8.	Chaukhutia	Rainfall	8	29° 52' 32.1" N 79° 22' 15.6' E	976	Forest Conservation Department, Ranikhet
9.	Kedar	Rainfall	8	29° 47' 07.8' N 79° 15' 26.8" E	958	Forest Conservation Department, Ranikhet

No.	Met/rain gauge station	Data fields Monthly	Period (years)	- Latitude - Longitude	Elevation (meter)	Source
10.	Naula	Rainfall	8	29 ° 44’ 13.5” N 79 ° 15 11.8” E	886	Forest Conservation Department, Ranikhet
11.	Tamadhaun	Rainfall	8	29 ° 50’ 49.0” N 79 ° 12’ 05.4” E	912	Forest Conservation Department, Ranikhet
12.	Sauni	Rainfall	8	29° 37’ 47.9” N 79° 22’ 05.8” E	1599	Forest Conservation Department, Ranikhet
13.	Deolikhet	Rainfall	8	29 ° 38’ 51.1” N 79 ° 27’ 00.6” E	1715	Forest Conservation Department, Ranikhet
14.	Binta	Rainfall	8	29 ° 47’ 10.0” N 79 ° 28’ 14.5” E	1887	Forest Conservation Department, Ranikhet

Table 2. Mean Temperature v/s Elevation Relationship

Month	Regression Equation	R^2
January	y = - 0.0031 x + 14.106	0.89
February	y = - 0.004 x + 17.012	0.95
March	y = - 0.0047 x + 22.122	0.97
April	y = - 0.0051 x + 27.95	0.96
May	y = - 0.0057 x + 31.485	0.98
June	y = - 0.0059 x + 31.925	0.96
July	y = - 0.0058 x + 30.642	0.99
August	y = - 0.0054 x + 29.755	0.98
September	y = - 0.0053 x+ 28.855	0.99
October	y = - 0.0044 x + 25.133	0.95
November	y = - 0.003 x + 19.284	0.89
December	y = - 0.0018 x + 15.045	079

Table 3. Scaling of moisture index into different agro-climate types

Climatic type	Moisture Index	Symbol
Semi arid	-66.7 to – 33.3	D
Dry sub-humid	- 33.3 to 0	C1
Moist sub-humid	0 to 20	C2
Humid (4 classes)	20 to 100	B1, B2, B3 and B4
Per-humid	> 100	A

Vegetation Biomass variability

Using NDVI to estimate standing green biomass proved to be a reliable source of biomass data. The existing functional relationship between monthly cutting of green dry matter (DM) and maximum normalized difference vegetation index (NDVI) derived from NOAA AVHRR (Advanced Very High Resolution Radiometer) was used. Monthly NDVI images of NOAA AVHRR during year 1999 were used to derive the maximum NDVI in a year for estimating biomass or dry matter (DM) as per equation.

$$DM = (1.615 * NDVI_{max})^{1.318} \; ; \; R^2 = 0.90$$

DM = Dry matter

$NDVI_{max}$ = Maximum NDVI in a year.

Land use/land cover

Land use/land cover was derived from coarse resolution IRS WiFS satellite data. Ground truth was collected through integrated use of previous year IRS LISS III hard copy (1:250,000 scale) satellite data, Survey of India (SOI) toposheets and handheld Global Positioning System (GPS). Combination of satellite data acquired during *kharif* (September and October, 2001) and *rabi* (January and March, 2002) seasons were digitally classified to land use/land cover information classes for *kharif* and *rabi*, respectively using MXL classifier. Agricultural land use classes in *rabi* season were refined with respect to land use information in *kharif* season and crop calendar of major crops cultivated in the region. Finally, classified land use /land cover information of *kharif* and *rabi* seasons were logically integrated on a pixel by pixel basis in raster GIS for deriving cropping system or composite land use/land cover (Fig. 3).

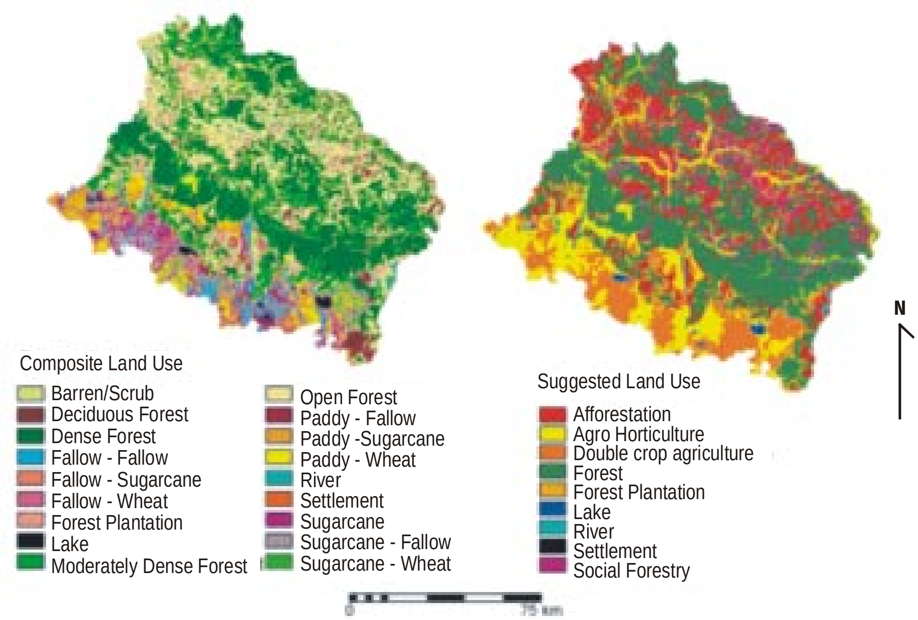


Figure 3: Suggested land use based on AEZs and present land use

Soils

Forty-six soil mapping unit along with their characteristics such as depth, texture, slope, erosion status, and drainage condition for the study area were obtained from soil map (1:250000 scale) prepared by National Bureau of Soil Survey and Land Use Planning, India. These spatial and non spatial data on soils were converted into digital soil resource databases for AEZ. In general terms, coarse loamy and skeletal soils are in side slope and top of Lesser Himalayas and piedmont plain while fine textured soils mainly found in alluvial plain and fluvial valleys. The soils are mostly moderately deep to deep, however, approximately 25 % of the area having shallow soils were mainly found in Lesser Himalayas and piedmont plain (Fig. 4).

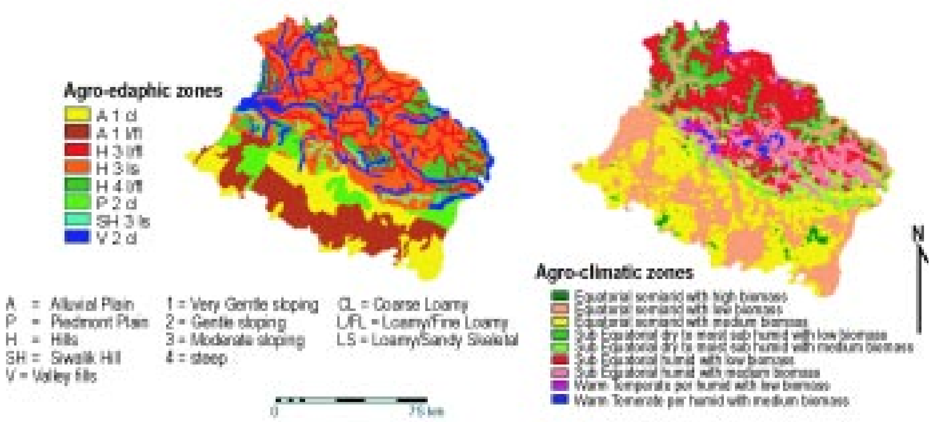


Figure 4: Characteristics of agro-edaphic and agro-climatic zones

All the land resource databases and characteristics (Fig. 1) described above as layer or combination of layers of spatial information were integrated or overlaid to derive different unique agro-ecological cells. These agro-ecological cells were further aggregated to arrive at agro-ecological zones and sub zones based on their potential to support agriculture and vegetation patterns.

Delineation of agro-climatic zones

Agro-climatic zones are of paramount importance for defining or delineation of agro-ecological zoning for sustainable use of land resources. The essential elements in demarcating or defining of an agro-climatic zone are bioclimates based on thermal regimes, moisture regime and biomass variability

(Fig. 5). Thermal regimes indicate to the amount of heat available for plant growth and development during the growing period. Moisture regimes represent water availability for crop production and hence they are the vital to classify the agro-climatic zones. Nine different agro-climatic zones were delineated by GIS aided integration of thermal regimes, moisture regimes and biomass map layers (Fig. 5).

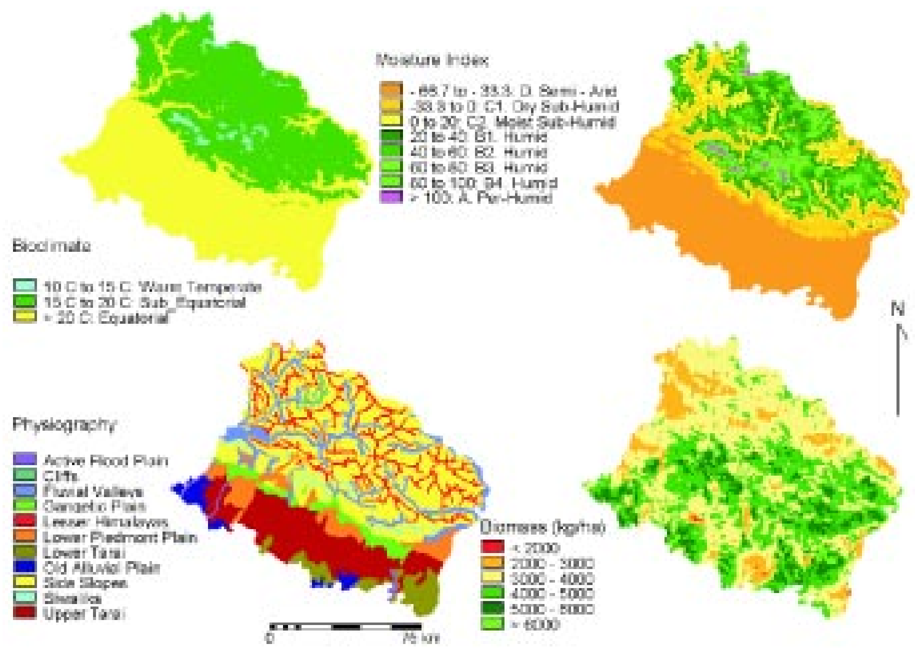


Figure 5: Input layers for agro-ecological zoning

Delineation of Agro-ecological zones and sub-zones

Thirty agro-ecological sub zones (AEZIa to AEZXIIc) were delineated in the study area (Table 4) by GIS aided integration of nine agro-climatic and eight agro-edaphic zones (Fig. 6). Results revealed that the majority of area falls in XIa whereas minimum area is occupied by Via (Patel *et al.*, 2002). The other larger sub-zones are Ib and VIIIa, respectively. AEZIc and AEZIIc are the most potential zones for intensive cropping with possibility of two and three crops such as paddy – wheat or sugarcane – wheat (Table-4). Further sub-ecological zones are reclassified by GIS aided integration in which sub-zones are clubbed into main agro-ecological zones. Therefore, twelve agro-ecological zones (AEZI to AEZXII) are identified in the study area. The spatial

Table 4. Spatial extent of Agro-Ecological Sub Zones

Sl.No.	AEZ	AE Sub Zone	Description	Area (ha)	(%)
1.	I	a	Equatorial, semiarid very gently sloping alluvial plain with loamy to fine loamy soils and low biomass	74487.48	6.50
2.	I	b	Equatorial, semiarid very gently sloping alluvial plain with loamy to fine loamy soils and medium biomass	107997.1	9.42
3.	I	c	Equatorial, semiarid very gently sloping alluvial plain with loamy to fine loamy soils and high biomass	10111.92	0.88
4.	II	a	Equatorial, semiarid very gently sloping in alluvial plain with coarse loamy soils and low biomass	80015.28	6.98
5.	II	b	Equatorial, semiarid very gently sloping in alluvial plain with coarse loamy soils and medium biomass	64135.22	5.59
6.	II	c	Equatorial, semiarid very gently sloping in alluvial plain with coarse loamy soils and high biomass	2371.58	0.21
7.	III	a	Equatorial, semiarid gently sloping valley fills with coarse loamy soils and low biomass	46335.98	4.04
8.	III	b	Equatorial, semiarid gently sloping valley fills with coarse loamy soils and medium biomass	24758.47	2.16
9.	III	c	Equatorial, semiarid gently sloping valley fills with coarse loamy soils and high biomass	77.76	0.01
10.	IV	a	Sub equatorial, Sub humid to humid gently sloping valley fills with coarse loamy soils and low biomass	34531.08	3.02

Sl.No.	AEZ	AE Sub Zone	Description	Area (ha)	(%)
11.	IV	b	Sub equatorial, Sub humid to humid gently sloping valley fills with coarse loamy soils and medium biomass	11631.71	1.01
12.	V	a	Equatorial, semiarid gently sloping piedmont plain with coarse loamy soil and low biomass	42151.25	3.68
13.	V	b	Equatorial, semiarid gently sloping piedmont plain with coarse loamy soil and medium biomass	34266.01	2.99
14.	V	c	Equatorial, semiarid gently sloping piedmont plain with coarse loamy soil and high biomass	968.43	0.08
15.	VI	a	Sub equatorial, Sub humid to humid gently sloping piedmont plain with coarse loamy soils and low biomass	7.07	0.00
16.	VI	b	Sub equatorial, Sub humid to humid gently sloping piedmont plain with coarse loamy soils	1180.48	1.10
17.	VII	a	Warm temperate, per humid moderately steep to steep sloping piedmont plain with coarse loamy soils and low biomass	5444.59	0.57
18.	VII	b	Warm temperate, per humid moderately steep to steep sloping piedmont plain with coarse loamy soils	6976.9	0.61
19.	VIII	a	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loam to fine loam soils and low biomass	123103.1	10.75
20.	VIII	b	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loam to fine loam soils	65662.08	5.72

Sl.No.	AEZ	AE Sub Zone	Description	Area (ha)	(%)
21.	IX	a	Equatorial, semiarid moderate steep to steep sloping in Hills with loam to fine loamy soils and low biomass	35354.6	3.08
22.	IX	b	Equatorial, semiarid moderate steep to steep sloping in Hills with loam to fine loamy soils and medium biomass	15561.97	2.67
23.	IX	c	Equatorial, semiarid moderate steep to steep sloping in Hills with loam to fine loamy soils and high biomass	498.35	.05
24.	X	a	Warm temperate, per humid moderately steep to steep sloping Hills with coarse loamy skeletal soils and low biomass	2286.76	0.20
25.	X	b	Warm temperate, per humid moderately steep to steep sloping Hills with coarse loamy skeletal soils and medium biomass	3990.33	0.34
26.	XI	a	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loamy skeletal soils and low biomass	182201.9	15.88
27.	XI	b	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loamy skeletal soils and medium biomass	106272	9.27
28.	XII	a	Equatorial, semiarid moderate steep to steep sloping Hills with loamy skeletal soils and low biomass	2940.62	0.26
29.	XII	b	Equatorial, semiarid moderate steep to steep sloping Hills with loamy skeletal soils and medium biomass	43830.09	3.82
30.	XII	c	Equatorial, semiarid moderate steep to steep sloping Hills with loamy skeletal soils and high biomass	353.44	0.03

Table 5. Spatial extent of Agro-Ecological Zones

Sl.No.	AEZ	Description	Area (ha)	(%)
1.	I	Equatorial, semiarid very gently sloping in alluvial plain with loamy to fine loamy soils	192596.5	16.8
2.	II	Equatorial semiarid very gently sloping in alluvial plain with coarse loamy soils	146522.1	12.78
3.	III	Equatorial, semiarid gently sloping in valley fills with coarse loamy soils	71172.21	6.21
4.	IV	Sub equatorial, Sub humid to humid gently sloping valley fills with coarse loamy soils	4842.13	4.03
5.	V	Equatorial, semiarid gently sloping piedmont plain with coarse loamy soil	77385.69	6.75
6.	VI	Sub equatorial, Sub humid to humid gently sloping piedmont plain with coarse loamy soils	1187.55	1.10
7.	VII	Warm temperate, per humid moderately steep to steep sloping piedmont plain with coarse loamy soils	12421.49	1.18
8.	VIII	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loamy to fine loamy soils	188765.2	16.47
9.	IX	Equatorial, semiarid moderate steep to steep sloping in Hills with loam to fine loamy soils	51414.92	6.80
10.	X	Warm temperate, per-humid moderately steep to steep sloping Hills with coarse loamy skeletal soils	6277.09	0.54
11.	XI	Sub equatorial, Sub humid to humid moderate steep to steep sloping Hills with loamy skeletal soils	288474.2	25.15
12.	XII	Equatorial, semiarid moderate steep to steep sloping Hills with loamy skeletal soils	47124.15	4.11

distribution of these zones is presented in Figure 6. The area covered ranges from 0.54 % in AEZ X to 25.15 % in AEZ XI. The whole hilly portion falls in AEZ VIII whereas lower alluvial plain in AEZ I and AEZ II (Table-5). A suitable land use (Fig. 3) plan for sustainable use of land resource for the Kumaon region was suggested based on characteristics of AEZs and existing land use pattern.

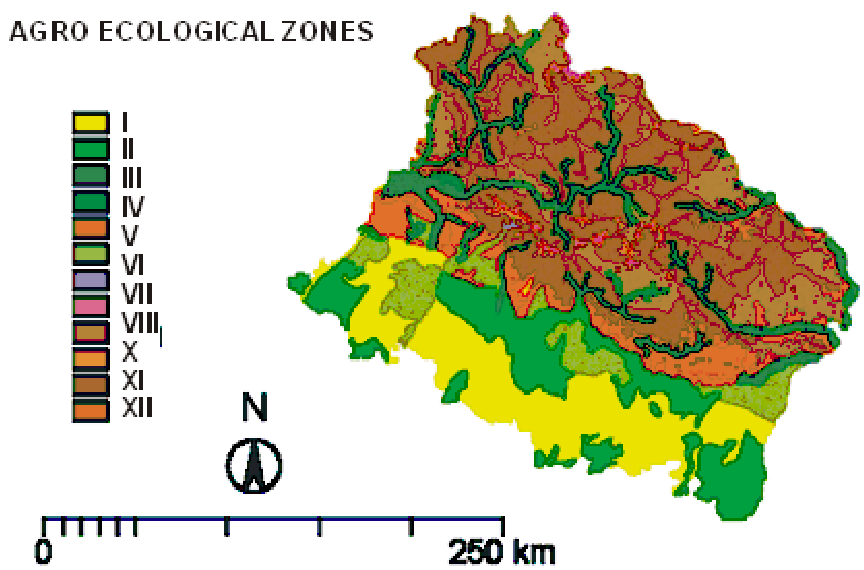


Figure 6. Agro-ecological zones

CONCLUSIONS

A Remote Sensing and Geographical Information System based approach to delineate Agro-Ecologically homogeneous geographical areas was developed using soil resources, temperature, rainfall, moisture, and biomass as input layers. Based on delineated Agro-ecological Zones, suitable land use were suggested in Kumaon region of Almora, Nainital, Champawat and Udham Singh Nagar districts.

Following conclusions were drawn from the study,

1. Strong negative relations between temperatures and elevation (i.e. lapse rate) would provide basis for estimating spatial variations in temperature, particularly in the mountain ecosystems.

2. Spatial distribution of PET and Moisture index would help in defining micro-Environment more accurately in the mountains environment.

3. Integration of bio-climate, moisture regimes and regional vegetation biomass in GIS environment could provide a more dynamic way of characterizing homogeneous agro-climatic zones for identifying biophysical and climate characteristics to agricultural productivity.

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