CHARACTERIZATION OF AGRO-ECOLOGICAL ZONES OF PUNJAB STATE USING REMOTE SENSING AND GIS TOOLS

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KEYWORDS: Thermal, LGP, Biomass, Agro-ecological, Zone, Punjab, India.

ABSTRACT:

Agro-ecological zoning for the entire state of Punjab was carried out using modern tools such as remote sensing and geographical information system. The main input parameters based on which zoning was done were annual average temperature, length of growing period (LGP), biomass and soil texture. Initially, spatial database for temperature, LGP, biomass and soil texture were generated in GIS domain. Thermal and LGP zones were demarcated using meteorological data of 20 stations of Punjab and its surrounding states. Then biomass zones were derived from 10-day composite satellite data of SPOT-vegetation sensor. This zoning approach resulted into 5, 7, 3 and 9 zones for temperature, LGP, biomass and soil texture, respectively in GIS environment. Those newly drawn zones reflect that the average annual temperature of the state varies from 21-26oC, with LGP ranging from < 60 to 180 days. Temperature and LGP variation in the entire state depicted a reverse trend, having maximum temperature in south-western part with lowest LGP while lowest temperature being recorded in the northern most parts with highest LGP. On the basis of NDVI value, the entire state was differentiated into moderate, good and excellent biomass zones. Soil texture varies from fine loamy to sandy soils across the state. Overlaying of thermal and LGP layers resulted into 7 thermal-LGP zones and when this layer was overlaid on biomass and soil textural layers in spatial domain following logical combinations, the resultant layer was agro-ecological zones. In total 46 zones were categorized in ZBS format where Z, B and S represented thermal-LGP, biomass and soil texture zones, respectively.

1. INTRODUCTION

The state of Punjab and its farmers, once at the centre stage of green revolution, are facing serious problems of sustaining agricultural productivity. The problems facing the farmers can be viewed in relation to three distinct regions / situations of the state; (i) the central rice-wheat cropping zone where declining water table and overall resource degradation (soil and water quality), (ii) the canal irrigated southwestern zone, the cotton-wheat belt, is the region where ground water is brackish in nature, a factor limiting their exploitation for irrigation and (iii) the ecologically fragile Kandi region, is distinct in that the problems facing farmers relate to recurrent droughts, wide spread problems of resource degradation and consequently, continued low level of overall socio-economic development (Abrol, 2008).

During the course of time, due to intensification of agriculture, the cropping pattern of the state has changed drastically. The whole state is progressing towards a rice-wheat mono cropping system from the multi crop – husbandry practices. As rice is a high water demanding crop, the effect is visible on the water balance in different districts of the state. Water logging and secondary salinity are the other consequences of indiscriminate use of good quality and marginal quality waters for irrigation. (PRSC, 1997).

Thus to sustain the food security of the Indian Punjab, it is of great importance to delineate the state into different zones according to the climatic requirements and soil types. 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 (Venkateshwarlu *et al*, 1996). Therefore, there is an urgent need for agro-ecological zoning of the entire state.

The success of zoning a particular region lies in adoption of new research tools available, particularly the vital inputs from space technologies such as remote sensing (RS) and geographic information systems (GIS) (Steven 1993). Remote sensing technology has been of great use to planners in planning for efficient use of natural resources at national, state and district levels. Agroclimatic zoning for Punjab in the past involved manual integration of agroclimatic and other natural resource data (Mavi, 1984). As a result, large amount of agro-ecological data could not be handled easily. This led to the loss of information on spatial variability. Modern tools such as satellite remote sensing and GIS have been providing newer dimensions to effectively monitor and manage the natural resources in spatial domain.

Also, the enormous growth of agriculture and land use/land cover change coupled with increased intensity of surface irrigation in this part of the country and the change in global climate contributing factors have led to change in climate at various places of Punjab in the last decades. (Hundal and Kaur, 2002; Mukherjee *et al*., 2003).

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Thus in the changing climatic, land use scenario and advent of modern technologies, the present investigation "Agro-ecological zoning using remote sensing and geographical information system for the Punjab state" was planned.

2. MATERIALS AND METHODS

The present investigation was carried out in the department of Agricultural Meteorology, Punjab Agricultural University, Ludhiana in collaboration with Punjab Remote Sensing Centre, Ludhiana during the years 2006 and 2007. The study area was the state of Punjab, India.

Location of study area

The Punjab State, with a geographical area of 50,362 sq. km, lies between the latitude of 29° 33' to 32° 31' N and longitude of 73° 53' to 76° 55' E. Three broad socio-cultural regions of Punjab are, *Majha* - land between the river Ravi and Beas; Bist Doab – land between river Satluj and Beas; and Malwa – land east of river Satluj.

Collateral data

Administrative boundaries (state and district) at 1:50,000 scale from Survey of India (SOI) maps and soil map at 1:500,000 scale prepared by National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), modified/simplified by Punjab Remote Sensing Centre.

Satellite data (SPOT 10-day composite NDVI images)

Remote Sensing data of SPOT-vegetation sensor 10-day cumulative NDVI product. In total 72 composites per year were used starting from June 1, 2004 to May 21, 2005 and from June 1, 2005 to May 21, 2006. Spatial resolution of 1 km and spectral bands of Blue (0.45-0.52µm), Green (0.52-0.59µ), Red (0.62-0.69µ) and Infra red (0.72-0.78µ) were available in the images for analysis.

Climatic data

Daily weather data of rainfall and minimum temperature and maximum temperature were collected from different sources representing different existing agroclimatic regions of Punjab and its neighbouring states as per the availability of data (20 meteorological stations).

Potential Evapotranspiration (PET) calculation

PET calculation was done by Papadakis method as it requires only daily maximum and minimum temperature data and is the most effective method among different empirical methods used at different locations representing different agro-climatic regions of Punjab (Kingra and Hundal, 2002).

Length of Growing Period (LGP) calculation

Lengths of growing periods (LGPs) in individual years were calculated using Excel spreadsheet for the period of time that P+S exceeds 0.5 ETp. The yields of many common crops decline markedly if the soil moisture falls below this level. The soil moisture storage capacity was assumed to be uniform throughout the state, because a particular soil type was considered irrespective of rainfall and PET zones.

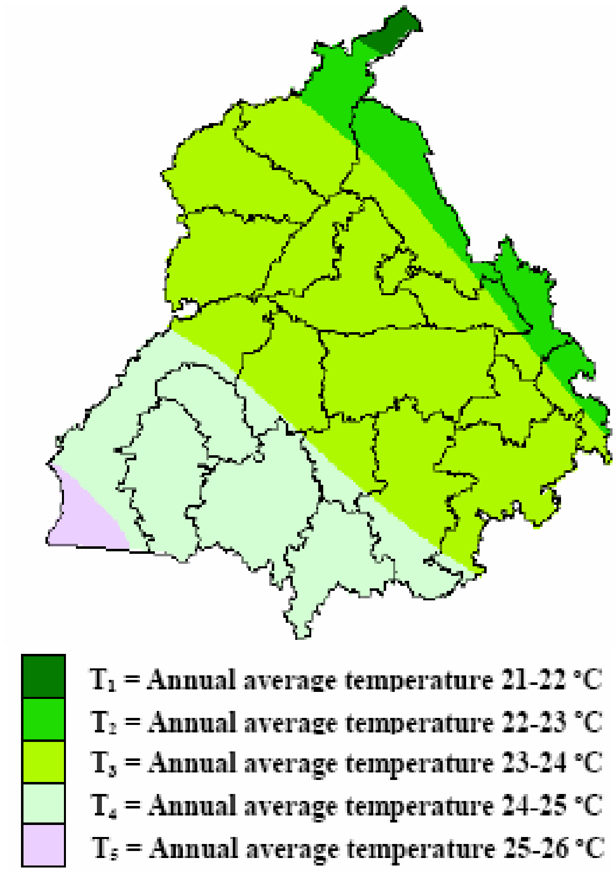
Potential biomass zone estimation from SPOT NDVI

Using NDVI to estimate standing green biomass is a reliable method of assessing biomass data. Lower resolution (1-km) SPOT-NDVI data for the years 2004-05 and 2005-06 were used as it gives continuous and synoptic coverage plus the availability of data on the Internet.

These NDVIs were considered as potential biomass indicators on a regional scale. The NDVI analysis was done for different date satellite scenes. Then the output of the different scenes was integrated to generate a single state biomass zone using NRSA guidelines (NDVI <0.06, Non Agriculture; 0.06-0.10, Poor; 0.10-0.20, Moderate; 0.20-0.40, Good; >0.40, Excellent) (Anonymous, 2006).

Thermal and LGP maps

Thermal and LGP maps (Fig. 1) were prepared in the GIS environment using Arc GIS - 9.1.



Length of growing period zones of Punjab

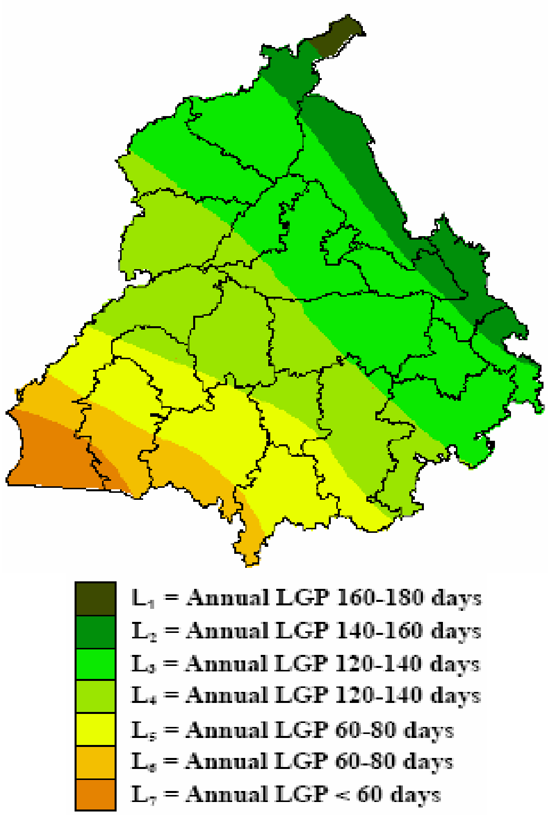


Figure 1. Delineation of Different Zones for Punjab

Thermal_LGP Layer Overlaying

Both layers of thermal zone and LGP zones were rasterized using vector to raster module of Arc/Info. Both these raster based spatial data bases were created at 1km grid size. Different intersections and unions were the resultant of the overlaying of the two layers. To finalize the layers redigitization of the intersection zones were done and final zones were demarcated. This raster based spatial database of Thermal_LGP zone was then imported into a separate image channel using image processing software (PCI Geometica 9.17).

Agro-ecological Zone Delineation

Agro-climatic zone was delineated by overlaying the Thermal_LGP layer over the potential biomass zone layer on a logical combination in RS software. Agro-ecological zones and sub-zones were delineated by logical combination of soil texture layer in addition to all the spatial input layers used in defining agro-climatic zones. In the output layer, similar to agro-climatic zoning approach, smaller polygons representing same agro-ecological zones closely placed were merged together into a single large polygon having similar properties.

3. RESULTS AND DISCUSSION

Compilation of Climatic Resource Inventory

The climatic resource inventory comprises of layer information on temperature and Length of growing period (LGP).

Thermal Layer

A spatial coverage layer was generated using point data on temperature in Arc GIS. In the present study, five thermal zones have been defined based on temperature intervals of 1°C across the zones. Average annual mean temperature ranges from 21°C to 26°C. The high-lying areas over the extreme north and north-eastern parts of the state record relatively low temperatures representing zones T_1 and T_2 ($\leq$ 23 °C) and in the low-lying south-western arid zones (T_4 & T_5) temperature is $\geq$24 °C. The high temperature in the south-western parts of the state may be due to the proximity to the Thar desert, scanty rainfall and lack of sufficient vegetative covers. The lower temperature in the northern part may be ascribed to its higher latitudinal location and its proximity to the foot hills of Himalayas (Siwalik hills). Most of the areas of the state however lies with in the moderate thermal zones of T_2 (22-23°C) to T_4 (24-25°C). Area under T_3 zone was highest followed by T_4 zone and the least area under T_1 zone.

Length of Growing Period (LGP) Layer

The LGP data of different meteorological stations were fed into GIS environment and through spatial interpolation method (krigging) LGP surface layer map was generated. Altogether seven LGP zones were categorized ranging from < 60 days to 180 days with an interval of 20-days (Fig 1). Maximum number of days (L_1=160-180 days) with sufficient moisture for crop growth was found in the extreme northern part of Gurdaspur district of Punjab. This was mainly due to the occurrence of higher rainfall and lower ET demand. The lowest number of days (L_7 < 60 days) lies in the extreme south-western parts of the state comprising southern parts of Firozpur and Muktsar districts. This may be attributed to occurrence of less rainfall, higher temperature and subsequent high ET demand. Most of the areas of the state however lie with in the moderate LGP zones of L_5 (80-100 days) to L_2 (140-160 days). The maximum area was under L_3 followed by L_4 and L_5. The least area was under L_1 zone.

Compilation of Present Land Resource INVENTORY

The land resource inventory comprises of information on soils and potential biomass zones.

Soil Textural Layer

A soil surface textural map of Punjab state representing 8 major textural classes at a scale of 1:250,000 was generated in GIS environment at PRSC, Ludhiana through field survey (Fig 1). This spatial map on soil texture was used as an input layer in defining agro-ecological zones. The mapping units reflect as precisely as possible the soil texture of the entire state. Although soil textural classes do not represent land characteristics, yet in a regional scale study, it has is significance significant in the use and management of land. The soil textural classes vary from sandy skeletal to fine loamy with major area falling under the class of coarse loamy texture.

Potential Biomass Layer

Physically it is nearly impossible to visit the whole state to identify the potential biomass zones. However with the introduction of remote sensing based NDVI classification approach, identification of potential biomass zone in spatial environment seems to be cost effective and time saving technology.

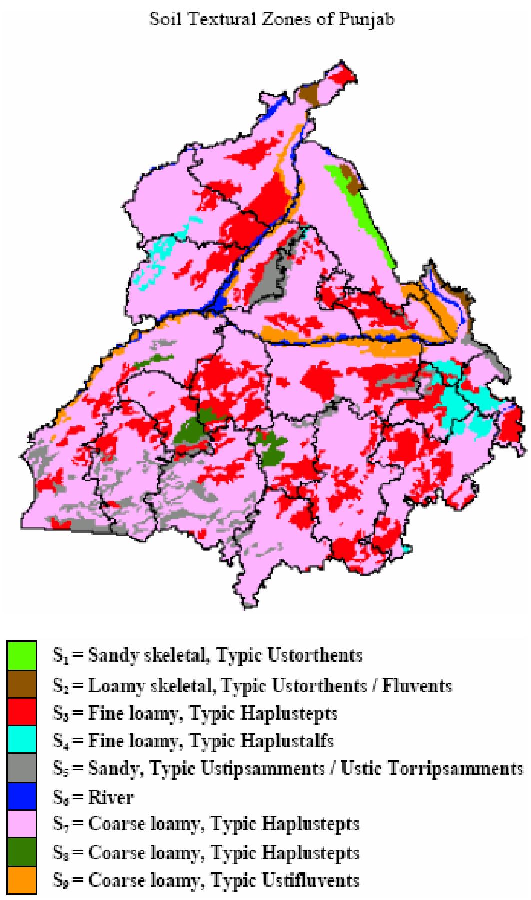
The use of NDVI to estimate standing green biomass is a reliable source of biomass data. Ten-day composite NDVI images of SPOT data during the years 2004-05 and 2005-06 were used to derive the biomass for three different seasons (*kharif*, *rabi* and summer). Based on NDVI values, the biomass layer was categorized into four categories each for r*abi* and kharif season and three categories for summer season. The integration of these three season based layers (*kharif*, *rabi* and summer), resulted into a single biomass zone for the Punjab state (Fig 1). On the basis of biomass potentiality, the whole state was divided into three categories as moderate (B_M), good (B_G) and excellent biomass zone (B_E).

Delineation of Thermal-LGP zones

Thermal layer comprises of five zones and LGP layer comprises of seven zones. Through logical combinations of these two layers in raster module of Image processing software (PCI Geomatica) seven Themal-LGP zones for the state of Punjab was generated (Fig 1). For convenience in carrying out further analysis, these seven zones have been represented as Z_1, Z_2 … Z_7. Zone 1 (Z_1) comprises only extreme northern parts of Gurdaspur district. Zone 2 (Z_2) comprises northern parts of Gurdaspur, Hoshiarpur, Rupnagar and SAS Nagar districts of Punjab which has temperature range of 22-23 ^oC and LGP varies from 160-180 days. Z_3 and Z_4 have similar thermal climate (23-24 ^oC) but different LGP values (120-140 and 100-120 days). These include districts of Amritsar, Tarn Taran, Ludhiana, Jalandhar, Kapurthala, Patiala and sangrur. Z_5 and Z_6 (Muktsar, Faridkot, Bathinda, Mansa) were having similar thermal (24-25 ^oC) but different LGP zones (80-100 and 60-80). The last zone (Z_7) was the driest and hottest zone having annual average temperature of 25-26 ^oC and LGP less than 60 days. It is confined to the southernmost part of Firozpur district.

Delineation of Agro-Ecological Zones

Basically it was the Thermal-LGP zone on which biomass zone was overlaid. Based on this logical combination between biomass and Thermal-LGP zones an Agro-climatic layer comprising seventeen zones was delineated. When the Agro-climatic layer was superimposed on potential biomass and soil layer comprising of nine zones, the resultant layer was the agro-ecological zone layer. Based on this, the state of Punjab was divided into forty-six (46) agro-ecological zones (Fig 2). These zones are represented in the format such as $Z_xB_yS_z$ where, Z_1 … Z_7 represents the Thermal-LGP zones; B_M, B_G and B_E represents the biomass zones; S_1 …S_9 represents the soil textural classes.



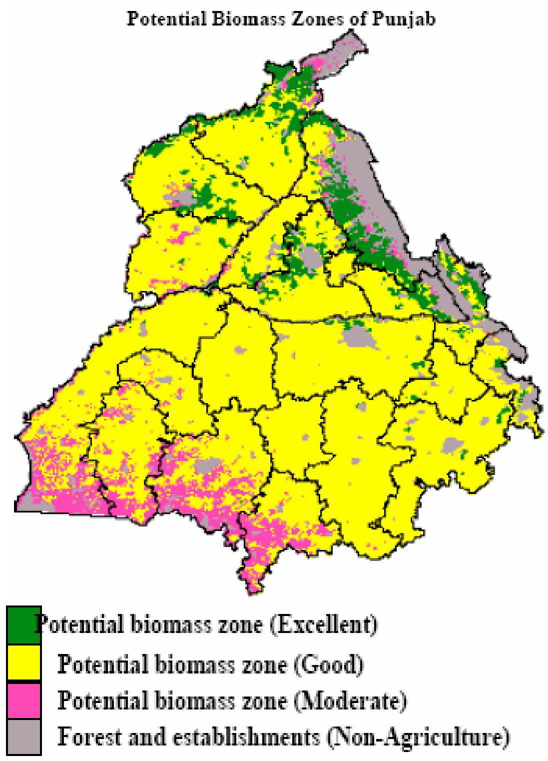
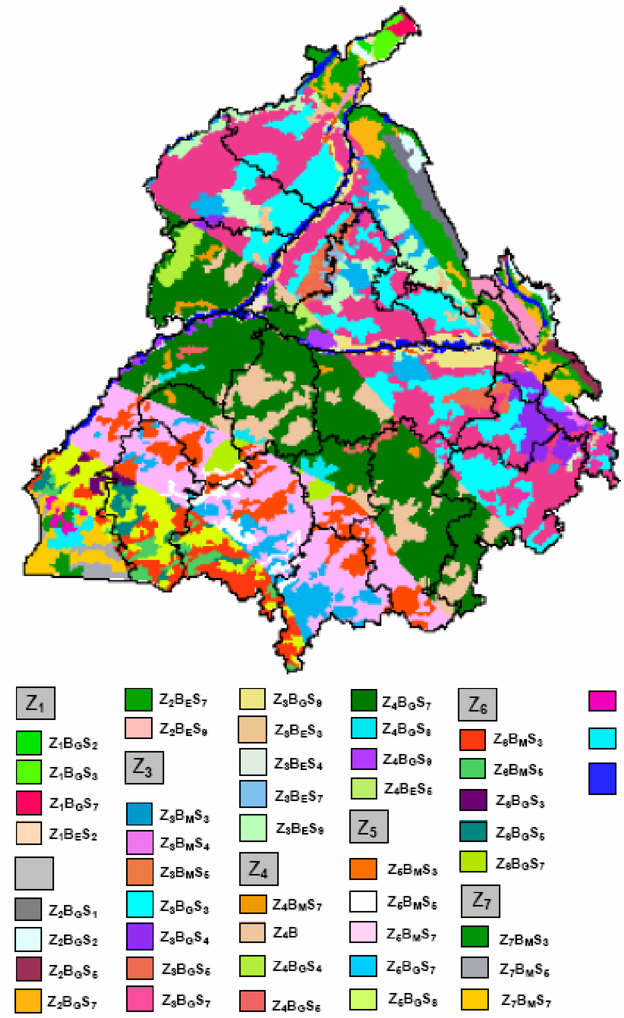


Figure 2. Agro-Ecological Zones of Punjab



CONCLUSION

The Agro-ecological zoning approach resulted into 5, 7, 3 and 9 zones for temperature, LGP, biomass and soil texture, respectively in remote sensing and GIS environment for the Punjab state. By using logical combination approach, in total 46 Agro-ecological zones for the Punjab state were delineated.

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