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Land resource requirements for bioenergy in India

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This study presents a two stage process to determine suitable areas to grow fuel crops: i) FAO Agro Ecological Zones (AEZ) procedure is applied to four Indian states of different geographical characteristics; and ii) Modelling the growth of candidate crops with GEPIC water and nutrient model, which is used to determine potential yield of candidate crops in areas where irrigation water is brackish or soil is saline. Absence of digital soil maps, paucity of readily available climate data and knowledge of detailed requirements of candidate crops are some of the major problems, of which, a series of detailed maps will evaluate true potential of biofuels in India.

Keywords: Bioenergy, GEPIC model, Land resources

Introduction

In India, 75% of villages were electrified as on March 2005 but only 54.9% of households had access to electricity and 75% of households still depend on fuelwood for cooking[1]. Energy demand is expected to quadruple in another 25 years[2]. One way to meet this energy need is to use fuel crop fired combined heat and power (CHP) plants. These would deliver electricity to villages that need it while providing heat for cooking using the same fuels that are already used by 75% of households. In India, for political and social reasons, land suitable for food production cannot be used exclusively for fuel production. Geographical Information Systems (GIS) offer an innovative way to determine the suitability of a location for differing agricultural land uses. This paper presents combination of GIS, database management techniques and crop water models to determine potential for bioenergy in 4 states (Rajasthan, Haryana, Uttar Pradesh and Uttarakhand) of northern India. It determines land requirements for biofuels production to run effectively small generating plant (size, 100kW).

Experimental Section

Energy, Biomass and Land Area Requirements

In general, two types of biomass [woody biomass (poplar, eucalyptus etc.) and agricultural residues (rice husk, wheat straw, etc.)] can be considered for fuel use in India. Much experimentation has been done to determine calorific values (higher heating values, HHV) of biomass fuels. HHV can be calculated from formulae based on proximate analysis of materials[3] and directly using differential scanning calorimetry (DSC) method[4]. A fuelwood value index[5] (FVI = calorific value + density / ash content) takes into account the desirable and non desirable factors of fuelwood and can be used to rank the suitability of different species for use as fuel. Plant species[6] in India that have high FVI values include *Pinus kesiya* (HHV, 19.09 MJ kg^{-1}), grown widely for timber in India in both natural forest and plantations, and *Acacia auriculiformis* (HHV, 20.25 MJ kg^{-1}), already widely used as a fuel. Also suitable are various species of poplar [mainly *Populous deltoids* (HHV, 19.09 MJ kg^{-1})] in India, known for its fast growth, easy vegetative propagation and soil enrichment qualities[7]. Hybrid poplars (HHV, 19.38 MJ kg^{-1}) have also widely been tried as a feedstock and have calorific values similar to those of other woody and herbaceous biomass feed-stocks[8]. To illustrate the potential for use as biomass in India, *P. deltoides* will be used as it is the most common species of poplar in India with more than 16000 ha of plantations in Tarai region of central Himalaya alone. On an 8-y rotation[7] in one of the region's, agroforestry plantations yielded 202.59 t ha^{-1}, which equates to 329, 4113. MJ ha^{-1} in 8-y or 411764 MJ ha^{-1} per annum or 114,400 KWh. So, 1 ha of *P. deltoids* could run a 100

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KW plant for 114.4 h assuming 100% efficiency. Thus, to run a 100 KW plant for 1 y approx. 76 ha of *P.deltoides* are needed. Hybrid poplar, with higher energy content and greater yields based on a shorter rotation (British)[9], could reduce this to 43 ha. Estimated available land for biomass production in India is 42.6-130 million ha[10]. There is, therefore, significant potential for bioenergy in India, but location and plant choice need careful consideration. Practically, 100% efficiency cannot be obtained from electrical generating plant, and for electrical generation even efficiencies of 60% are only possible from largest thermal power stations. Combined heat and power allows for up to 80% efficiency.

Land Evaluation (LE)

LE is a process whereby all possible uses for a location are evaluated. However, it is generally taken to refer primarily to agricultural uses, rather than urban or industrial. Principles of LE were laid down in over a number of years in the 1970s by Food and Agricultural Organisation (FAO) of United Nations[11]. LE for fuel crops should look at the possibility of restoring degraded land and for political reasons not use land already used for food production. LE can be split into two different modelling strategies: i) A heuristic approach, whereby it is assumed that all crops have the potential to deliver their maximum yield; and ii) A growth modelling scheme to take a specific crop, or rather a plant and simulate how it grows under prevalent environmental conditions. Therefore, LE for present study has following two parts:

i) *Agro-Ecological Zoning (AEZ) Method*[12] *using Modern GIS Modelling Techniques* % This is international standard for carrying out large scale LE and is thus highly relevant to this study. AEZ methodology assesses suitability of land for growing crops, treating each factor (temperature, soil etc.) as separate and independent from others when calculating suitability. Suitability is ultimately determined by potential yield. This part will also involve assessing risk of growing crops at each locality due to environmental hazards such as growing a fast rotation crop on land that floods is less risky than growing a slow rotation crop in terms of the potential loss to grower[12-15]. AEZ approach is implemented as a series of SQL statements within the database management component of GIS.

ii) *Using GEPIC*[16-18] *to Model Potential Crop Yields with Emphasis on Water Availability as Limiting Factor* % GEPIC integrates a bio-physical EPIC model (environmental policy integrated climate) with a GIS package and can be used to model crop production and crop water relations over a large area. GEPIC was designed to be used with ArcGIS by ESRI and this combined with VBA interface and ready incorporation of Microsoft access database management system made it obvious choice for GIS software for both applications.

Data Requirements for Land Evaluation (LE)

Climate Data

Climate data are absolutely essential to any agricultural land evaluation because all crops will only grow within specific boundaries of temperature, moisture and radiation. High resolution climate data (both spatially and temporally) are even more important for modelling potential yields of crops as maximum production can often only be achieved in narrow boundaries of above factors. Though it is best to have raw station data to fully understand the data set and process it specifically for LE purposes, these data are difficult to obtain. At the very least interpolated data with a detailed explanation of interpolation methods used would be acceptable, the best source of that data is the work from Tyndall Centre for climatic research at the University of East Anglia that provide a gridded data set for India at 10 minute resolution (approx. 118 km)[19]. Since climate data is highly elevation dependent, further interpolation to a finer grid is required using digital elevation model and MODIS and ASTER remotely sensed climate data[20,21].

Soil Data

Resolution of the data should be reasonably high to reveal enough details relevant to a plot (size, 3 or 4 ha). Additionally, too high a resolution would require very large amounts of time to digitize and process. With these considerations, due to the size of areas being evaluated, soil maps should be 100 m resolution, with perhaps a lower resolution for Rajasthan, the largest state. However, soil maps are normally available in following resolutions: 10 m, 1:50,000; 100 m, 1:5,00,000; and 200 m, 1:10,00,000 scale. The 1:10,00,000 maps will not have sufficient detail. The 1:50,000 are produced for areas of specific interest such as good agricultural land. They show individual soil series but the large number of small individually mapped areas introduces considerable computational difficulty with large states such as Rajasthan. Possible incomplete coverage, excessive computational effort required and doubts about appropriateness of modelling techniques with such fine scale data rule out the use of 1:50,000 scale mapping for this project. As the smallest plots of land required for the production of biofuels will be 1 ha, 100 m resolution combined with computational efficiency and near universal availability of 1:5,00,000 scale maps makes them the most appropriate for this study. Soil mapping units should ideally follow World reference base (WRB)[22] for soil resources taxonomy and each contain a detailed profile of soil series within it. Individual soil series can be unmapped within soil associations or soil mapping units. For each series, following parameters are required[22]: 1) Soil group, classification and taxonomic code as determined by soil profile; 2) Depth, texture, drainage, density, sand/clay/silt content, if these are not made implicit by the series, besides factors affecting workability such as presence of stones, phases or pans and their effect on root depth and drainage; 3) Fertility (high, medium, low), as defined by FAO, should be sufficient, again this is often determinable from soil classification, however this will also depend on potassium and Nitrogen content; 4) pH; 5) Chemical content ($CaCO_3$, CEC, organic carbon); 6) Salinity; 7) Metal toxicity; and 8) Slope (%) would be useful for validation of present slope calculations from digital elevation model (DEM).

No digital survey maps were available for the study area, so paper maps were aquired from National Bureau of Soil Survey and Land Use Planning, New Delhi, India for Uttar Pradesh (old boundary including Uttarakhand) and Haryana. These were then scanned at a resolution of 300 dots per 2.54 cm (1 in.) ready for digitisation.

Topographical Data

Topography of land is important to LE as again crops have preferences towards differing levels of slopes. Slope and aspect affect amount of radiation the land receives. It also affects soil type, depth and risk of erosion. Additionally, some crops will only grow at specific elevations, although this is mainly because elevation affects the climate. A DEM of the area is sufficient to calculate slope and aspect[23]. Ideally it should be the same resolution as soil maps and has to tie in with plot sizes used in universal soil loss equation. It needs to be as detailed as soil maps in order that all slopes relevant to the size of plots are mapped. Shuttle Radar Topography Mission (SRTM)[24] provides digital elevation model for this project at 90 m resolution.

Land Use

Current land use is useful in LE because: i) This will be used as a filter to eliminate land units currently used for food production; and ii) To verify LE. If LE indicates that land currently being used for wheat is unsuitable for wheat production then there is clearly something wrong. Land use can be obtained from remotely sensed data from USGS/NASA's MODIS, ASTER and Landsat[25] satellites. All Landsat data in USGS archive are now available free of charge.

Land Management and Crop Yields Data

Irrigation and fertilizer maps are needed as an input to GEPIC. Irrigation, fertilizer and pesticide application data may be very hard to obtain due to the way that fertilizer use is recorded in India. Data in India are taken on the district level by surveying a sample of 200-300 farmers in the district, usually half from hills and half from plains. The problem here is that unless data contains names of villages, where farmers were from, then pure data will be useless and district averages will be used. When it comes to yield, the practices of farmers may cause a lot more variability than environmental factors. These are not confined to quantifiable factors (amounts of fertilizer used, pesticides, and irrigation) but also unquantifiable factors (how serious the farmer is, how knowledgeable he is and other economic and social issues). These factors can cause large local variations in yield that are not related to environment. The way round this is to take average yields of farms surveyed in each village area. This way local variability is minimised so that differences in yield between villages that are caused by environment are more prominent. In addition, irrigation and fertilizer maps will help minimise the variation caused by unquantifiable data. These are also helpful for use in GEPIC to model the potential yields and CWP. These data are for GEPIC and not AEZ methodology. If irrigation and soil maps are unobtainable, datasets for high, medium, low inputs will be created and these will be used to model what crop yields and CWP would be obtained compared to no management.

Crop Database

This database contains potential crops to be grown and soil and climatic parameters required to grow such crops. This should not only contain parameters required for optimum growth but also a range of conditions that will produce some yield. Currently, the data for 1710 crops has been downloaded from FAOs Ecocrop database[26], which contains following parameters for each crop: i) Min. and max. growing period (d); ii) Killing temperature (°C); iii) Min. and max. growing temperatures (°C); iv) Min. and max. temperatures for

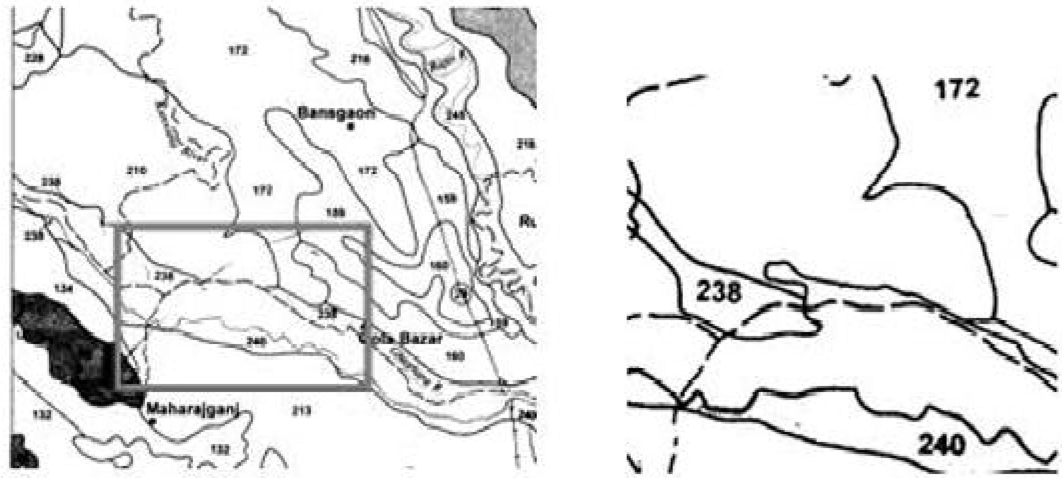

Fig. 1—Soil map indicating disappearance of river (left) and tracing of river (right)

optimal growth (°C); v) Min. and max. rainfall to grow (mm); vi) Min. and max. rainfall for optimal growth (mm); vii) Light intensity at optimum and absolute growing limits; viii) Photoperiod (long, neutral, short); ix) Photoperiod min. and max. hours daylight; x) Optimum and absolute soil texture (light, medium, heavy, organic); xi) Optimum and absolute depth (deep, medium, shallow); xii) Optimum and absolute drainage (poor, well, excessive); xiii) Min. and max. soil pH; xiv) Min. and max. pH for optimal growth; xv) Optimum and absolute salinity (low, medium, high); and xvi) Optimum and absolute fertility (low, medium, high). These data alone lack precision required for either AEZ or GEPIC approaches. Previous evaluations such as Kenyan AEZ[14] are done in more detail for fewer crops; if this information can be found then a broader study can be carried out with Ecocrop and then information for more important crops can be found in more detail.

Results and Discussion

Digitizing Progress

The most efficient method with regards to time-scale and accuracy for digitizing maps has been assessed and a time-scale established. In a semi-automatic method, features on map are traced by hand but lines drawn will snap to pixels. In order to use snapping features, map was converted to a black and white binary image by using threshold feature in any good image processing software (GIMP), which converts all light areas to white and all dark areas to black. In soil maps, some of the canals and rivers, which are often used as soil association boundaries (Fig. 1), have been removed. Artefacts from scanning can also be cleaned up at this point. Each individual map sheet needs to be geo corrected before it can be digitised. Main problems relating to digitizing of data are interlinking; that there are no gridlines or coordinates on the map and that there is no indication of how much features on the map are generalised. Absence of any geo referenced points on map means it cannot be accurately known where soils are located. This creates a problem for modelling and locating the positions of climate stations and it is very difficult to check using field and remote sensed data from other sources.

Use of other background features (roads and railways) on map offers some possibility for geo referencing the map, but this also proves difficult as there is no indication as to generalization of these features. Therefore, accurately plotting GCPs (ground control points) is difficult. As map contains highways and railway lines, junctions of these are being used as GCPs, with locations[27] being obtained from Google Earth^{tm}. However, many of the junctions on soil map are actually generalisations of many junctions in real life (Fig. 2). There are also only a limited number shown on soil map, so finding exact coordinate for enough GCPs is proving to be a major task to overcome. Some 1:1,000,000 historical maps that correspond to rail, river and road features in the soil map from the last pre-independence survey of India have been obtained. These maps have a lat-long grid, which can be geo referenced easily with < 100 m rmse. Features in these maps can then be

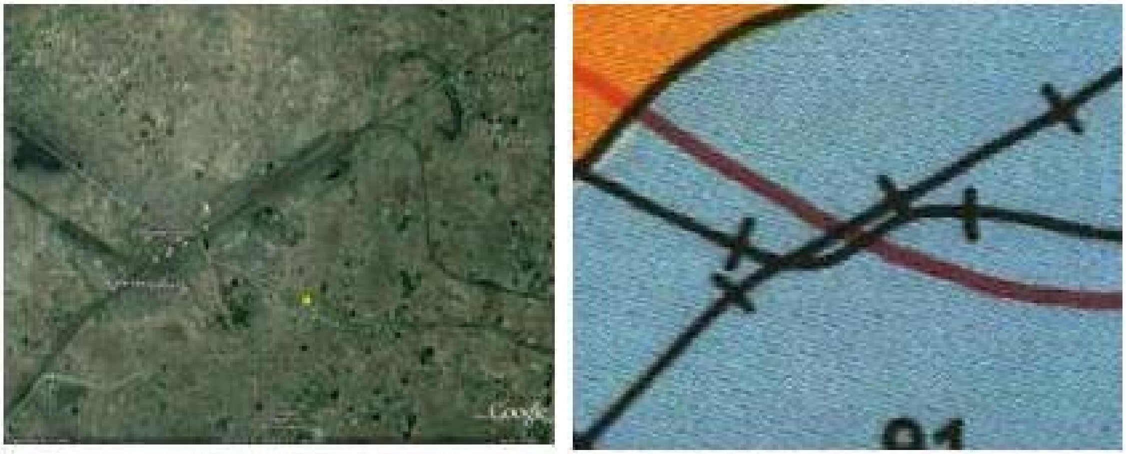

Fig. 2—Google Earth[tm] image (left) and soil map image (right) (railway lines cross each other in soil map, whereas they merge together in aerial image; Right hand branches off differently in aerial image than soil map. The main road crosses two railway lines in the map but only one in real image, and some bends have been removed in the soil map)

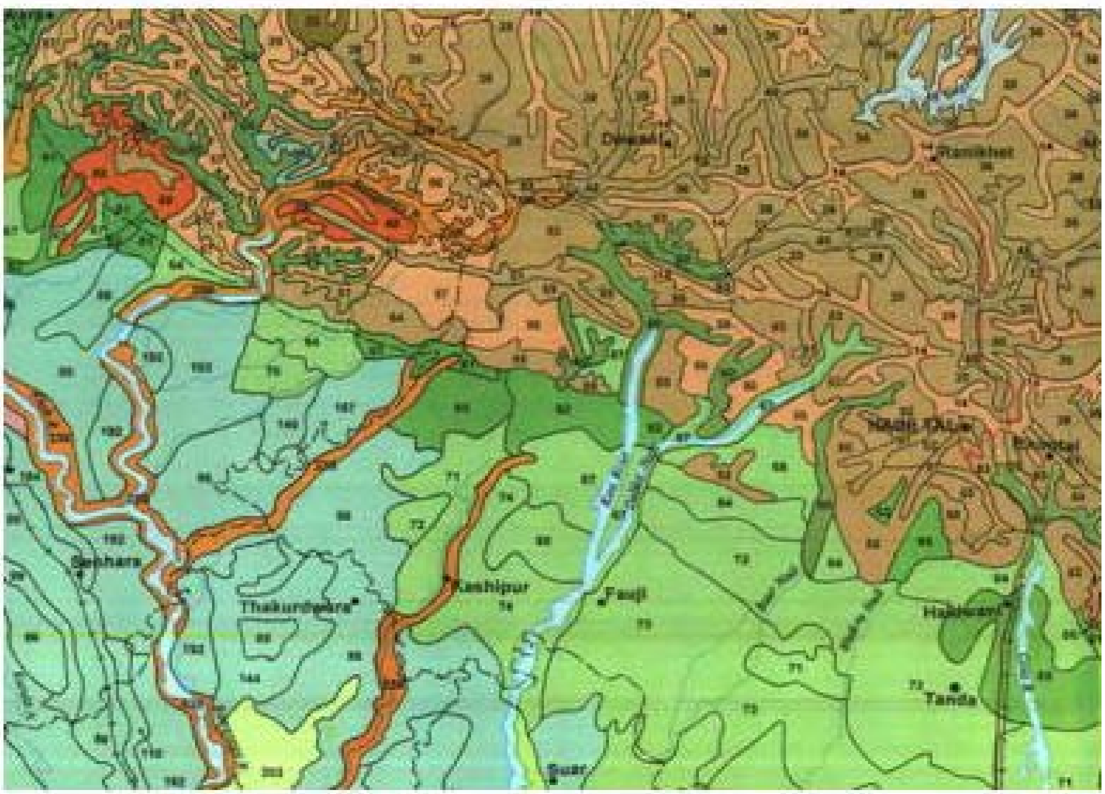

Fig. 3—Sample of Uttar Pradesh (UP) soil map showing difference between mountainous (top) and lowland (bottom) terrain

used to georectify the features in the soil map and thus the soil features themselves. These maps don't give the projection used. There are also US Army 1:250,000 maps of the area that do contain some projection information that can also be used for validation. These are proving better than the Google Earth approach. Root mean square of error of location should be in the order of 100 m, spatial resolution of original maps, but current experiments are giving higher values in the order of 2-800 m. From a single geo referenced map, each soil association was then traced into digital polygons using snapping feature in ArcGIS. This will take longer for complex hilly areas (Fig. 3). However, error checking is quick and easy using a geo database topology and identifying a correcting errors only took 10 min. Fig. 4 shows a part digitised map.

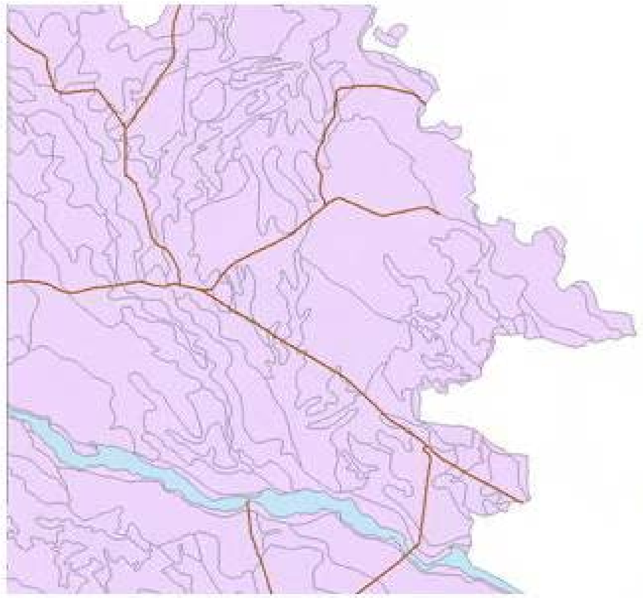

Fig. 4—Sample of digitized soil map (UP sheet 6) showing SMUs, water and railway lines

Conclusions

A combination of AEZ approach and a crop water modelling offers potential to evaluate land resources. It will also allow for unproductive land (saline soils or land containing brackish water) to be investigated for potential use. However, absence of digital soil maps will take a considerable programme of work to complete. Paucity of readily available climate data and knowledge of detailed requirements of candidate crops adds to these problems, as does the sheer size of areas being investigated. By the end of 3-y project, a series of detailed maps should be available to evaluate true potential of biofuels in India.

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