Geospatial Mapping of Bioenergy Potential in Karnataka, India

T. V. Ramachandra
Energy Research Group, Centre for Ecological Sciences, Indian Institute of Science
Bangalore 560 012, India
Email: cestvr@ces.iisc.ernet.in
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Abstract

Biomass energy is an important energy source for a majority of the world's inhabitants and continues to be a major source of energy and fuel in developing countries. Energy from biomass holds promise in the Indian conditions as it encourages self-reliance through efficient use of indigenous resources and employment of simpler technologies consistent with minimal possible hazards. It meets about 75% of rural India's energy needs. While, in Karnataka, non-commercial energy sources like firewood, agricultural residues, charcoal and cow-dung account for 53.2%. Using the Geographical Information System (GIS) data of bio-resource availability and demand, bio-resource status is computed for all taluks in Karnataka. The ratio of bio-resource availability to demand gives the bio-resource status. The ratio greater than one indicates bio-resource surplus zones, while a ratio less than one indicates scarcity. Bio-resource availability analysis shows that horticulture constitutes the major share at 43.6%, followed by forests (39.8%), agricultural residues (13.6%), animal residues (3.01%) and plantation (0.15%). Based on the bioenergy status and land use pattern, feasible management and technical options have been discussed, which help in optimizing the available bioenergy and in building a sustainable energy society.

Introduction

The risk of climate change due to emissions of carbon dioxide from fossil fuels is considered to be the main environmental threat from the existing energy system. Other environmental problems are acidification, and dispersion of metals originating from fossil fuels. Fossil fuels supply a large part of the total primary energy use in the world, about 76% [1]. Sustainable development of a region depends on the health of renewable energy resources like water, vegetation, livestock, etc. The integrated development of all these components is essential for environmentally sound development of the region. To strive towards a sustainable society would imply a shift to renewable energy sources, such as biomass energy. Biomass offers tremendous opportunity to use renewable and sustainable resources available locally to provide its fuel, power, and chemical needs from plants and plant-derived materials. Biomass sources supply about 35 and 3% of the primary energy needs of developing and industrialized countries respectively [2]. Due to its flexibility as an energy resource, biomass share in regional energy balances in this part of the globe is very significant [3-6].

Annually, 62-310 Mt of wood could be generated in India from the surplus land, after meeting all the conventional requirements of biomass, such as domestic fuel wood, industrial wood and sawn wood, with an investment of Rs. 168-780 billion. The annual energy potential of plantation biomass is estimated to vary from 930 to 4,650 PJ. It is projected that the energy consumption in 2010 will be 19,200 PJ; thus an estimate show that plantation biomass could supply about 5-24% of projected total energy consumption in 2010 [7]. The estimation of the biomass and the carbon contained in biomass of Indian forests, using species-wise volume inventories for all forest strata in various states indicate that the aboveground biomass densities ranged from 14 to 210 $Mgha^{-1}$, with a mean of 67.4 $Mgha^{-1}$, which equals around 34 $MgCha^{-1}$ [8].

Karnataka Renewable Energy Development Limited (KREDL) estimates the total biomass from agricultural activity is 66,979 tons/year, and the estimated biomass available from the agro-based industries is 3375 tons/year in Pandavapura taluk, Karnataka. This study has revealed that surplus biomass, capable of generating 19 million kWh of electricity per year through a 2.5 MW power plant, can meet 38% of energy requirement of the taluk, (including industrial power requirement) [9]. Decision support system (DSS) provides the tools to analyze spatially the biomass potential considering the theoretical, available, technological and economically exploitable potential. The main parameters that affect the location and number of bioenergy conversion facilities are plant capacity and spatial distribution of the available biomass potential [10].

A GIS based modeling system estimates the costs and environmental implications of supplying specified amounts of energy crop feedstock across a state, while estimating potential biomass supplies from energy crops in eleven US states. The system considers where energy crops could be grown, the spatial variability in their yield, and transportation costs associated with acquiring feedstock for an energy facility [11-12]. The spatial patterns of biomass and net primary productivity in China's forests using empirical data sets, remote sensing methods, and climate-vegetation models indicate that the present spatial pattern of NPP is a result of both natural environmental factors and human land use patterns. Estimates of NPP for the tropical zone (seasonal rainforests and rainforests) were highest, ranging from 20 to 24 Mg ha^{-1} $year^{-1}$. NPP was lowest in boreal zone forests comprised primarily of Scotch pine and Siberian pine, averaging only 6.7 Mg ha^{-1} $year^{-1}$ [13].

A recent study on energy utilization in Karnataka considering all types of energy sources and sector wise consumption reveals that, traditional fuels such as firewood (7.440 million tonnes of oil equivalent (MT)-43.62%), agro residues (1.510 MT-8.85%), and biogas and cow-dung (0.250 MT-1.47%) account for 53.20% of total energy consumption [14]. In Karnataka, the agriculture residues are used as fodder, fuel, thatch and manure. 92% of the stalk from crops is used as fodder, 4% as thatch, 2% as manure and 2% have other use. Major portion of the cotton stalk, groundnut shells, coconut shells and leaves are used as fuel [15]. The total cultivable area of the state including net sown area (55.06%), cultivable wasteland (2.28%), current fallows (6.66), and other fallows (2.10%) is 66.09%. The gross and the net cultivated area under agricultural crops had increased from 100.65 lakh hectares to 106.09 lakh hectares (1998-1999).

Firewood, is generally used as a traditional fuel, is got from the forests. The quantity of firewood released from the forest to the public for domestic and other uses in the year 2001, was around 109507 M^3. Forest cover since 1997 in Bangalore, Gulbarga, Hassan, Mandya, Mysore and Tumkur districts has increased. The total growing stock of Karnataka's forests is 272 million cubic metres. The average volume per ha is 84 cum, which is 10 cum more than the national average. The estimated increment of the forest produce in Karnataka is 5.5 m cum, and the productivity is 1.45 cum/ha annum for the whole area. For wooded area the productivity is 1.72 cum/ha/yr. The national average of productivity is 1.37 cum/ha [16]. The State has a total cattle population of 10.80 million, buffalo population of 4.4 million, goat population of 4.9 million and a sheep population of 8.0 million, and thus has an immense biogas potential. The solid content of dung is about 18% (82% moisture) and if 10% moisture is assumed, the dung cake potential on an annual basis is 123 Mt of air-dry weight. Dried dung has energy content anywhere between 8.5-14 MJ/Kg [17].

A host of factors like edaphic, meteorological, geographic and also to a certain extent the socio-economic status of the people influence the availability of bio-resources. Inventorying based on spatial aspects helps in identifying the reasons responsible for their inequality in distribution, availability and demand. This will also help the energy planners to incorporate appropriate conservation measures during policy interventions. Objectives of this study are:

i) To assess the taluk wise availability and demand of bioenergy in Karnataka
ii) Spatial mapping of bio-resource surplus and deficient zones.

Study Area

The study area, Karnataka State, is situated between 11°40' and 18°27' north latitude and 74°5' and 78°33' east longitude in the center of western peninsular India, covering an area of 19.1 Mha and accounts for 5.8% of the country's total geographic area. Fig. 1 shows the study area. It has a 350 km long coastline, which forms the western boundary. According to the 2001 provisional census the population of the State was 52.6 million (26.8 million males and 25.8 million females), with a rural population of 66.02% and an urban population of 33.98%. For the administrative purpose the State is divided into 27 districts, which are subdivided into 175 taluks. Out of the total geographical area (19.1 Mha) about 3.06 Mha of land is under forests (16.07%). The barren and non-agricultural land account for 10.99% of the total area. Other uncultivable land including cultivable waste and permanent pastures account for 9.10% of the total land. 8.755% of the total land comes under the fallow land. 64.62% of the total area comes under agriculture crops, while 9.56% is sown more than once. Karnataka is divided into 10 agro climatic zones taking into consideration the rainfall pattern quantum and distribution, soil types, texture, depth and physio-chemical properties, elevation, topography, major crops and type of vegetation. They are:

1) North Eastern Transition Zone (ACZ1).
2) Northeastern Dry Zone (ACZ2).
3) Northern Dry Zone (ACZ3).
4) Central Dry Zone (ACZ4).
5) Eastern Dry Zone (ACZ 5).
6) Southern Dry Zone (ACZ6).
7) Southern Transition Zone (ACZ7).
8) Northern Transition Zone (ACZ8).
9) Hilly Zone (ACZ9).
10) Coastal Zone (ACZ10).

Methodology

Bio-resource inventory helps in describing the quality, quantity, change, productivity and condition of bio-resources in a given area. These inventories may be for regional or national level assessments. Bioenergy status assessment is based on compilation and computation of bio-resource supply for the energy generation. Bio-resource availability is computed based on the compilation of data on the area and productivity of agriculture and horticulture crops, forests and plantations. Sector-wise energy demand is computed based on the National Sample Survey Organization (NSSO study) data, primary survey data and from the literature. Bio-resource supply from agricultural residue, forest, horticulture residue, plantation, and livestock dung are considered to assess the energy status taluk wise.

Forest inventory

For an assessment of forest biomass, forest inventory is most commonly used to measure forest biomass rather than or in addition to traditional volume. The forest inventory area is usually one or more management units, each ranging in size from a few hundred to many thousand hectares. Each unit may be divided into forest-based strata or administrative sub-populations for which separate estimates are required. The attribute of primary interest is merchantable wood volume, with stem frequency. Basal area data is of secondary importance. These attributes are usually given by tree size classes and by a number of forest and administrative classes that are described in a classification system such as the following:

- Total inventory area is divided into land and water
- Land is divided into forest and non-forest
- Forest is divided into productive forest and unproductive forest
- Productive forest is classified by ownership and status into forest and covers type, and by stands density, height, age, and site quality classes.

The information required for management inventories are obtained from the existent base maps, soil maps, and geological maps, narrative descriptions of the area and its history, remote sensing data, which are used to obtain information about individual stands, and field samples, from which detailed volume data are obtained through sampling procedures.

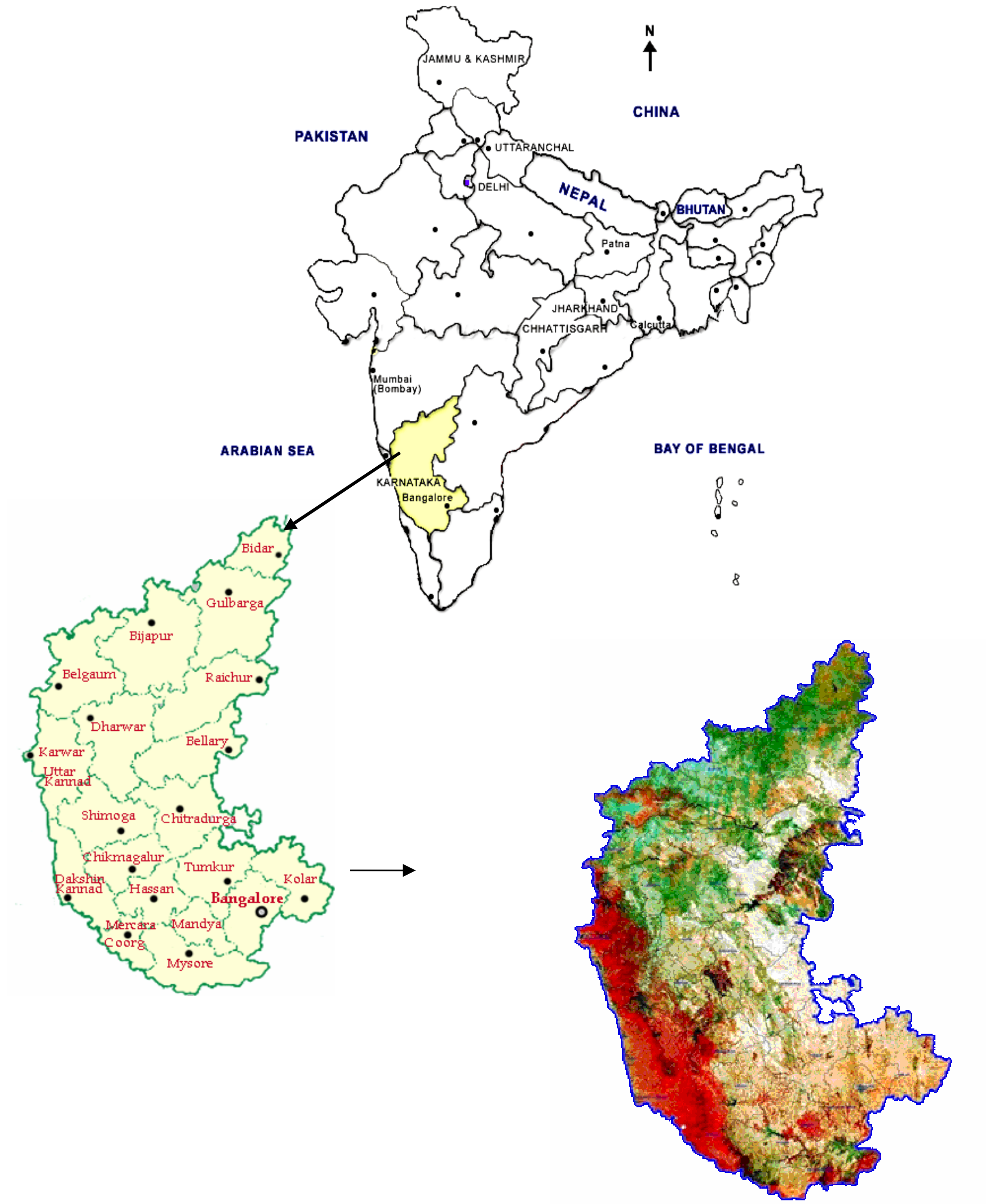

Fig. 1 Study area – Karnataka State, India

Above ground standing biomass of trees is the weight of trees above ground, in a given area, if harvested at a given time. The change in standing biomass over a period of time is called productivity. The standing biomass helps to estimate the productivity of an area and also gives information on the carrying capacity of land. It also helps in estimating the biomass that can be continuously extracted. The standing biomass is measured using the harvest method or by using biomass estimation equations. In the harvest method, vegetation in the selected sample plots are harvested and the weight is estimated in fresh and dry form to measure biomass. For trees, this method is inappropriate, as it requires their felling or destructive sampling. However, this could be computed by the knowledge of its height and girth (at 130 cm).

Standing biomass (in Kg) is given by $=b+ (aD^2H)$, where D is the diameter at breast height, H is the height of the tree, a and b are constants. Equations involving the basal area are used for all tree species and therefore are used to estimate the standing biomass of mixed forests. Productivity, which is the increase in weight or volume of any biomass over a period of time, can be estimated when the standing biomass estimates are available for two consecutive years. It can also be calculated by knowing the age of the forest stand in addition to the litter available annually. Productivity=standing biomass per hectare/age of a tree or the trees per forest stand. Productivity estimates are important as they help calculate the extent of biomass that can be extracted for fuel purposes.

Data on the land use pattern was collected from the Directorate of Economics and Statistics, Govt. of Karnataka. The major source of information on forest lands is the Karnataka forest department (KFD), which maintains a variety of records like the annual administration reports, working plans, forest inventory reports, which gave information on the growing stock, current status of these forests, the management practices adopted, plantations maintained and their prescribed felling cycle. The inventory of forest resources published by the Forest Survey of India (FSI) was also referred for this study. The forest area by types, given division wise in the forest records was used to compute the forest type at the taluk level. The biomass potential of the forests is dependent on the type of forest and its distribution cover. The biomass production varies with the type of the forest. The biomass productivity of the different types of forests are [14]. Dense evergreen and semi evergreen (13.41-27.0 t/ha/yr), Low evergreen (3.60-6.50), Dense deciduous forest (3.90-13.50), Savanna woodland (0.50-3.50) and Scrub (0.9-3.60). Using the low, high and average productivity values given above, the annual biomass production from each forest type was computed at the taluk level. Energy equivalent of 4000Kcal/Kg was taken for evergreen, semi-evergreen and moist-deciduous forest types, while for the dry deciduous and scrub type vegetation 4800Kcal/Kg and 3400Kcal/Kg were taken respectively. Total bioenergy from forests (Bio_1) is computed by

$$Bio_1 = \text{Bioenergy from forests (kcal)} = \text{Forest area} * \text{Productivity} * (\text{Energy equivalent}) \qquad (1)$$

Computation requires inputs such as forest types (i.e. Deciduous, Evergreen, etc.); respective spatial extent, annual productivity (tonne/hectare) and energy equivalent (kcal/tonne) and outputs would be annual bioenergy--forest type wise, region wise, etc.

Agro-residues inventory

The crop residue inventory involves the measurement of both crop yields and crop residues to allow the development of residue-yield ratio estimators as well as area-based estimates of residue yields. The ASF (Area Sampling frame) methodology provides a very efficient basis for estimating crop yields. This methodology involves the delineation of permanent or long-term sampling segments from satellite imagery (Multi spectral sensors). These are then used as sampling frames for subsequent agricultural surveys. The crop residues are surveyed during both the Kharif and Rabi season. Field sampling is carried out within one week before harvest to ensure that crop yield and residue measurements are related to fully mature crops. The cultivated area and the biomass yield of each crop influence the biomass potential from agriculture residues. The taluk wise area of the dominant crops cultivated in a taluk was collected from the state agriculture department for the last 6 years. Area under cultivation was not variety specific for a crop at the taluk level. The proportion of the area under high yielding variety and the traditional variety of a crop at the district level was used to segregate the area by variety at the taluk level. The grain yield and production figures for each crop were available only at the district level, which were used to compute the grain production at the taluk level. The yield of a crop (season and variety wise) across an agro climatic zone was obtained by averaging the yields of the previous six years (1995-2000). The ratio of the main product to the by-product for each crop grown under local conditions along with their energy equivalents were used to compute the agro residues production. The energy equivalent of these residues was taken based on what would be obtained if they were subjected to the most energy efficient transformation processes. Portion of the residues available are used as fuel, while some is used as fodder and the rest is left behind in the field for nutrient recycling. Apart from this, the actual availability of residues as energy supplements would also depend on other factors like efficiency of collection, mode of transportation and storage. Considering these, in the computation of bio-residue from agriculture only 50% is accounted for fuel. Bioenergy from agriculture residues (Bio_2) is computed by:

$$Bio_2\text{=Bioenergy from agriculture (kcal)} = \text{(Productivity of waste * Crop area* Energy equivalent)} \quad (2)$$

Computation of bioenergy from agricultural crops requires inputs such as crop type (i.e. Cotton, Green grams, etc.), spatial extent, crop yield or productivity, residue to crop ratio, energy equivalent (kcal/tonne), while outputs are annual energy--crop wise, region wise, etc.

Plantation inventory

The management of energy plantation would more closely resemble a farming operation than conventional forestry. Plantation inventory involves the assessment of spatial extent of plantation, type of plantation, annual productivity, mean annual increment and cycling time. Cultivation of chosen fuel wood species, which can be harvested during a short period of time, could meet the energy demand of growing population. The species are so chosen that they provide plenty of biomass, are fast growing, have good survival rate (high tolerance or adaptability, pest resistant and drought resistant) and produce large volumes of wood. Multipurpose species are mostly preferred. Selecting a leguminous species will also help maintain the soil fertility in addition to meeting the fuel wood requirements.

The area of plantations raised by the forest department under various schemes was obtained from the State forest department. Some of the commonly planted species are Casuarina, Acacia, Pongamia, Hardwickia binnata, Azadirachta indica, Leuceana leucocephala etc. Species wise extent and age of these plantations was not available even at the division level. However, the details of plantations raised on different sites, like canal side, roadside, in institutional premises etc available at forest department was used for computation. The biomass that could be obtained was calculated assuming that 30% were adult plantations. The yield of eucalyptus plantations in Uttara Kannada, Bangalore, Tumkur and Kolar districts were estimated to be 5 t/ha. The yield of Acacia auriculiformis plantations is known to be 10-34 m^3/ha. Based on these productivity figures, the biomass production of plantations was calculated using an average productivity of 5t/ha/year. Total bioenergy from forest plantation (Bio_3) is computed as:

$$Bio_3 = \text{Bioenergy from plantations (kcal)} = \text{Area * Productivity * (Energy equivalent)} \quad (3)$$

Requires inputs such as forest plantation types, respective spatial extent, annual productivity (tonne/hectare) and energy equivalent (kcal/tonne). Outputs are annual bioenergy--forest type wise, region wise, etc.

Horticulture

The area under the horticulture plantations of coconut, areca and cashew at the taluk level were obtained from the State horticulture department for the previous four years. The average yield figures of the district were used to compute the production at the taluk level. The fuel biomass from coconut and areca nut plantations along with the energy equivalent of the husk, shells, leaves and inflorescence were considered [14]. For the computation of the number of trees in the given area, tree count of 150/hectare and 1000/hectare were assumed for coconut and Arecanut plantations. Energy from horticulture (Bio_4) is computed by:

$$Bio_4 = \text{Bioenergy from horticulture (kcal)} = \text{Area} * \text{Productivity} * (\text{Energy equivalent}) \quad (4)$$

Computation requires input data such as crop type (i.e. Coconut, Arecanut etc.), spatial extent, number of trees per hectare, residues (leaf, shell, husk) actual count, anticipated use percent, conversion to weight (kg) and energy equivalent (kcal/kg), while output is annual energy--horticulture crop wise, region-wise, etc.

Livestock

The livestock population of cattle, buffalo, sheep and goat were collected from the state veterinary department. The quantity of dung yield varies from region to region. It was taken as 12-15Kg/animal/day for buffalo, 3-7.5 Kg/animal/day for cattle, 0.1 kg/animal/day for sheep and goat. The total dung produced annually was calculated by multiplication of the animal dung production per year and the number of head of different animals (FAO) taking the lower and higher dung yield. Assuming $0.036m^3$–$0.042m^3$ of biogas yield per Kg of cattle/buffalo dung, the total quantity of gas available was estimated. The per capita biogas demand varies across the agro-climatic zones. A per capita requirement of $0.34m^3$/person/day (zones 1-8), $0.43m^3$/person/day (zone 9) and $0.23m^3$/person/day (zone10) was taken for the computation of the biogas demand across the agro-climatic zones. Total bioenergy from livestock (Bio_5) is computed by:

$$Bio_5 = \text{Bioenergy from livestock (kcal)} = (\text{Biogas} * \text{Energy Equivalent}) \quad (5)$$

where, Biogas (m^3)= Biogas yield * Dung * 1000
and Dung (tonnes)= Dung yield * Population * 365 (for annual energy computation)

Data input to compute energy from livestock are livestock type (i.e. Buffalo, Cattle, Goat, etc.); population, dung yield (kg/animal/day), biogas yield (m^3/kg) and energy equivalent (kcal/m^3), and output would be biogas (m^3) and annual energy.

Total bio-resource available from various sectors is computed by aggregating the energy computed from individual sectors (forestry, plantation, horticulture, agriculture, livestock) and is given by,

$$\text{Bio-resource availability} = \sum_{i=1}^{5} (Bio_i) \quad (6)$$

where, i=1, 2…5 and Bio_1: Bioenergy from forest, Bio_2: agriculture, Bio_3: plantation, Bio_4: horticulture and Bio_5: livestock.

Bio-resource demand

Most of the bio-fuels consumed in rural areas (nearly 75%) are for domestic purposes mainly for cooking and water heating. The remaining is consumed by indigenous rural industries. Estimation of rural energy demand for domestic purposes was based on the state rural population, which was obtained from the provisional population total, Census of India 2001-Karnataka. Energy demand Survey results reveal that 80-85 % of the rural population is dependent on bioenergy and hence the demand was projected taking into account the entire rural population. Domestic fuel consumption depends on the size of the family.

Energy consumption patterns are seen to vary across geographical, agro climatic zones, seasons and the different economic strata of the society. The per capita fuel consumption is given by

$$PCFC = FC / P \quad (7)$$

FC is the fuel consumed in Kg/day and P is the number of adult equivalents, for whom the food was cooked. Standard adult equivalents of 1, 0.85 and 0.35 for male, females and children (below 6 years) respectively were used. The per capita values used for cooking and water heating across the agro-climatic zones are: hilly region (1.72 kg/person/day for water heating and 2.32 kg/person/day for cooking), coastal region (1.17 kg/person/day for water heating and 2.07 kg/person/day for cooking) and the remaining zones (1.02 kg/person/day for water heating and 1.85 kg/person/day for cooking (Please note the variation in consumption due to seasons has been accounted in this computation). In urban areas too fuel wood is used for domestic purposes by a smaller fragment of the population. The urban fuel demand was computed by taking a per capita value of 1.65kg/person/day for cooking and 1.07kg/person/day for water heating.

Conversion technologies

Besides satisfying the rural domestic energy requirements (cooking and water heating), biomass also finds use in the manufacture of construction materials like bricks, lime and tiles, and in agro-processing such as curing of tobacco, preparation of crude sugar etc. Cooking energy requirements are also met from cattle dung, leaf biomass from energy plantations and crop residues.

In comparison to the fossil fuels, fresh biomass has certain drawbacks like, high moisture content that reduces its combustion efficiency, low bulk density and lack of a homogeneous physical form. Biomass conversion helps to improve the characteristics of the material as a fuel. The conversion processes largely involve the reduction of the water content and improving the handling characteristics of the material. The energy so obtained can be used for domestic purposes, in agriculture, small scale industries like jaggery making, sericulture activities, coffee/tea processing, paper making, paddy drying etc. To exploit the energy content, the biomass feedstock is subjected to either physical, chemical, biological or thermo-chemical conversion processes.

Bioenergy was computed based on the data compiled from the Agriculture, Horticulture, Forest, and Veterinary departments of the State. These values were implemented in GIS to generate taluk wise bioenergy availability maps. The taluk-wise potential is evaluated using maps of administrative boundaries (taluk boundaries) and statistical data. The theoretical potential is presented as a thematic map of the total amount of biomass available in each region. The information contained in such a map can be used to identify regions where extensive cultivation is located and a more precise evaluation of the potential is justified.

Results and Discussion

Bio-resource availability

Resource wise analysis of the study area reveals that bio-resource from horticulture constitutes the major share of 43.6%, forest 39.8%, agriculture 13.3%, livestock 3.01%, and plantation.15%. Table 1 gives the percent bio-resource contributing to the total bioenergy.

Table 1 Total bioenergy in Mkcal and % contribution of each bio-resource

Bio-resource	Total energy, Mkcal	% Contribution
Agriculture	26560047	13.6
Forest	79431779	39.8
Horticulture	86871417	43.6
Plantation	312604.22	0.15
Livestock	5997527.8	3.01

Bioenergy from agriculture residue

Agriculture is the major source of biomass raw material either as agricultural by-products or as specially grown crops for energy use. The use of crop residue is wide spread in most parts of India. Agriculture is predominant in northern dry zone, which contributes the highest amount of agro residues and the bioenergy amounts to 10.59×10^6 Mkcal. Talukwise computation of bioenergy availability as illustrated in Fig. 2 indicates that Athani taluk (in ACZ3) in Belgaum district has highest energy (1.51×10^6 Mkcal) compared to Bantwal taluk (ACZ10) in Dakshina Kannada district that has the least potential (1147.72 Mkcal).

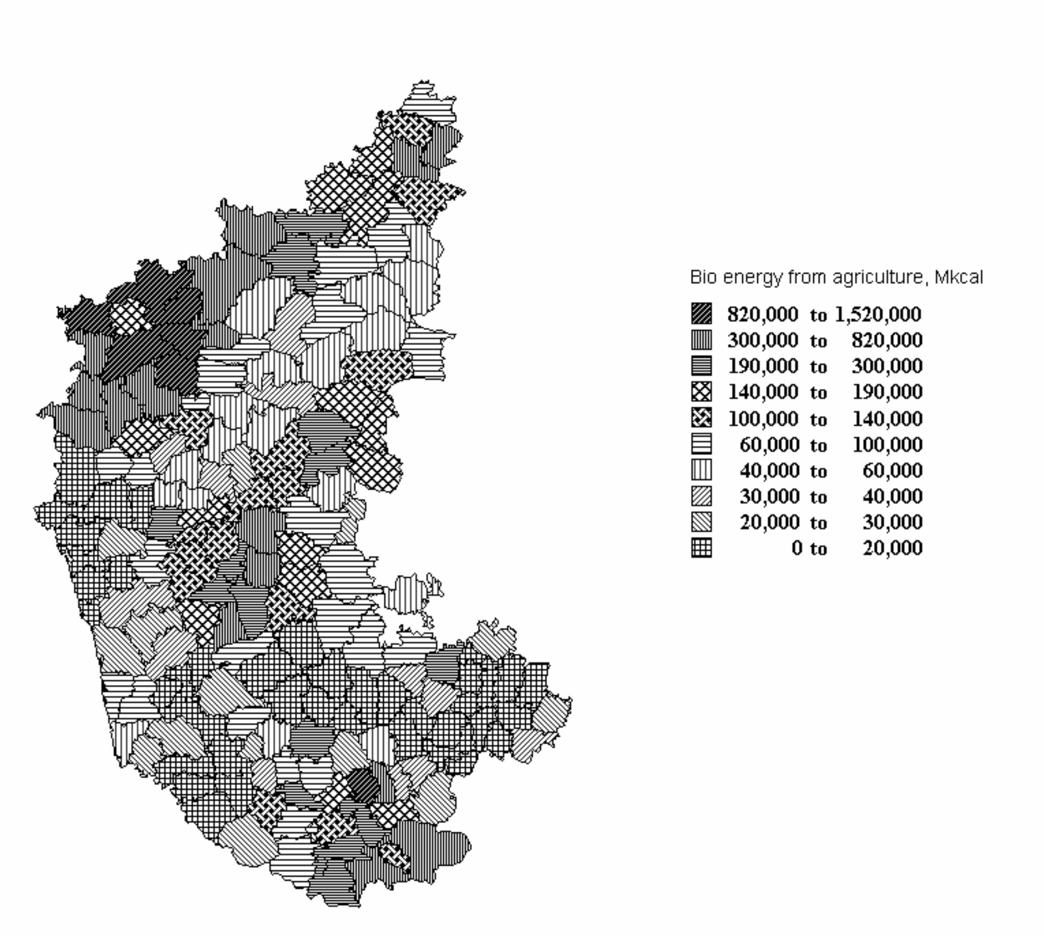

Fig. 2 Taluk wise distribution of bio energy from agricultural residue

Computation of percentage share of bioenergy to the total energy of the region reveals that taluks such as Athani (ACZ3), Mandya (ACZ6), Hosanagara (ACZ9), Jagalur (ACZ4), Belgaum (ACZ8) etc., have bioenergy > 80%. Compared to this, taluks such as Bangalore-North (ACZ5), Kadur (ACZ4), Tharuvekere (ACZ6), Bantwal (ACZ10), etc. have least contribution (<8%).

Bioenergy from forests

Forests are predominant in hilly and coastal zones contributing to the highest amount of bioenergy available. Talukwise computation of bioenergy availability from forests as shown in Fig. 3, indicates that, Kollegal (ACZ6) taluk in Chamrajnagar district has highest energy (5678778 Mkcal) compared to six taluks in the State where there are no forests and have least potential. Computation of percentage share of bioenergy from forests reveals that taluks such as Honnavar (ACZ10), Kollegala (ACZ6), Virajpet (ACZ9) etc. have bioenergy from forest residues >80%. Compared to this, Raichur (ACZ2), Maddur (ACZ6), Kundagola (ACZ 8), Indi (ACZ3), etc have least contribution (<1%) due to the absence of forests.

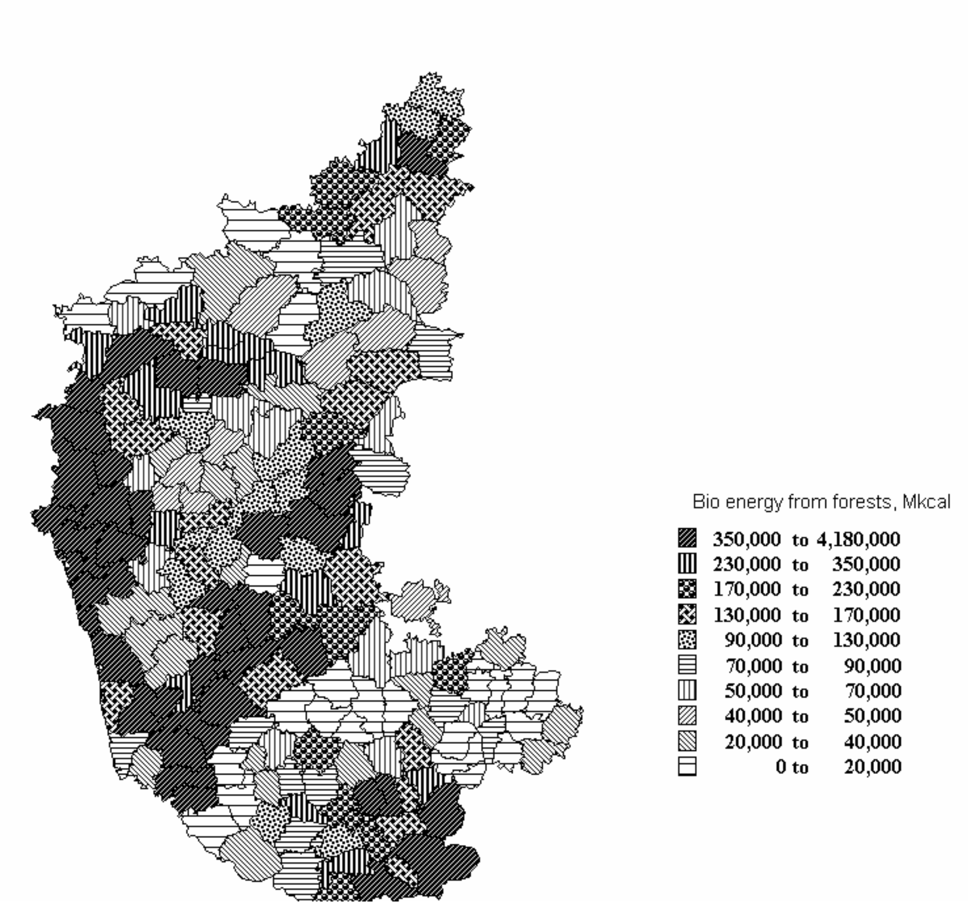

Fig. 3 Taluk wise distribution of bio energy from forest

Bioenergy from horticulture

Horticulture is predominant in coastal zone. The highest amount of bioenergy available from horticulture residues in this zone amounts to 25282919 Mkcal. Talukwise computation of bioenergy availability from horticulture as illustrated in Fig. 4 which indicates that Channagiri (ACZ7) taluk in Shimoga district yields maximum energy (7549933 Mkcal) and 5 taluks in Bidar (ACZ1) district yield no energy. Computation of percentage share of bioenergy reveals that taluks such as Belthangadi (ACZ10), Channagiri (ACZ7), Koppa (AGC9), Tharuvekere (ACZ6), Tumkur (ACZ5) etc. derive maximum (>80%) energy, when compared to taluks such as Navalagunda (ACZ3), Challekere (ACZ4), Aurad (ACZ1), Devadurg (ACZ2) where there is minimum or no energy derived from horticulture residue, as in these taluks coconut, areca and cashew plants are not grown.

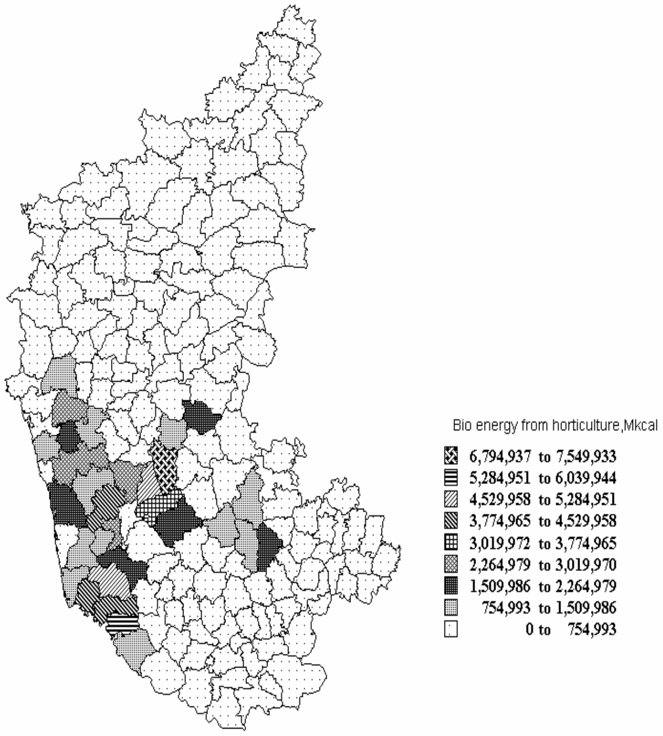

Fig. 4 Taluk wise distribution of bio energy from horticulture residue

Bioenergy from plantation

Plantation is predominant in hilly zone. The highest amount of bioenergy available from plantation in this zone amounts to 1141.29 Mkcal. Talukwise computation of bioenergy availability is illustrated in Fig. 5, which indicates that Sagar (ACZ9) taluk in Shimoga district (41607.5 Mkcal) yields maximum energy from plantation when compared to 75 taluks in the State with zero potential.

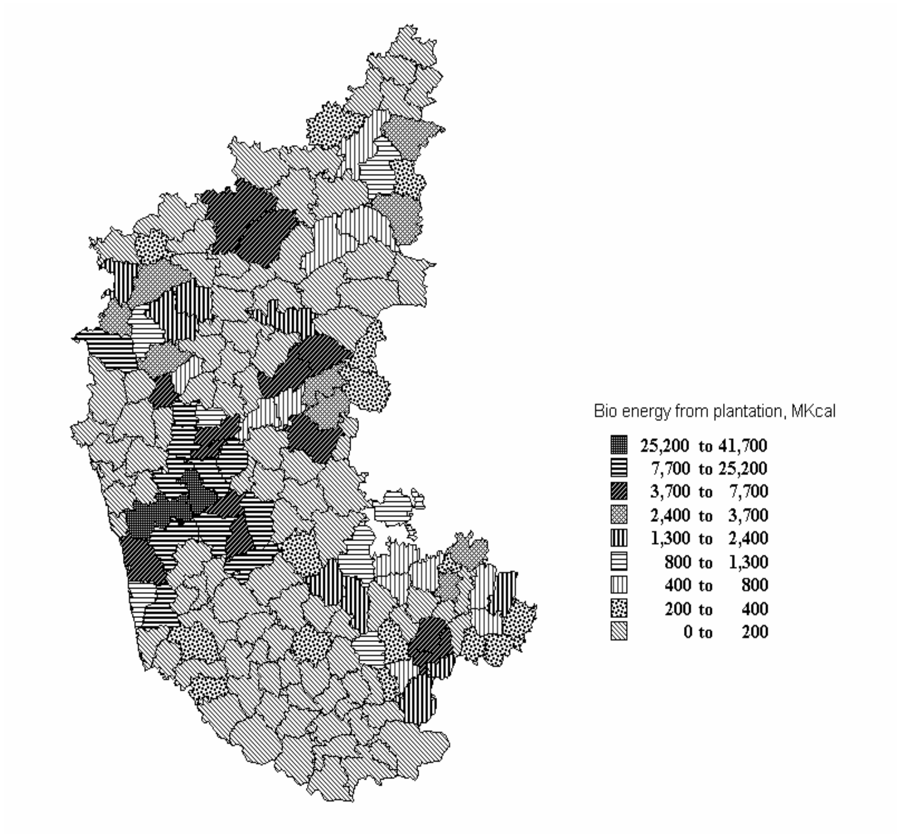

Fig. 5 Taluk wise distribution of bio energy from plantation

Bioenergy from livestock

Livestock is predominant in northern dry zone. The highest amount of bioenergy available from livestock in this zone amounts to 1361001Mkcal. Talukwise computation of bioenergy availability illustrated in Fig. 6 indicates that Raibag (ACZ3) taluk in Belgaum district (99588.87 Mkcal) has highest energy compared to Gudibanda (ACZ5) taluk in Kolar district (6438.28 Mkcal), which has the least potential. Computation of percentage share of bioenergy from animal residue shows that taluks such as Raibag (ACZ3), Bylhongal (ACZ8) etc. derive maximum bioenergy (>10%), compared to taluks such as Honnavar (ACZ10), Siddapura (ACZ9), Malur (ACZ6), Gudibanda (ACZ5) etc. that have least contribution (<1%). By considering taluk wise livestock population, lower dung yield figures, and annual biogas production the total dung available from cattle and buffalo is 11.83 million tonnes/year and 29.58 million tonnes/year respectively. Assuming the biogas (m^3) produced per Kg of the cattle/buffalo dung to be 0.036m3/day and taking the lower dung yield for each of the two, about 1114012196 m^3 of biogas can be produced annually. Using higher dung yields and higher biogas yields, the total amount of gas produced worked out to be 2245.6 x 10^6 m^3.

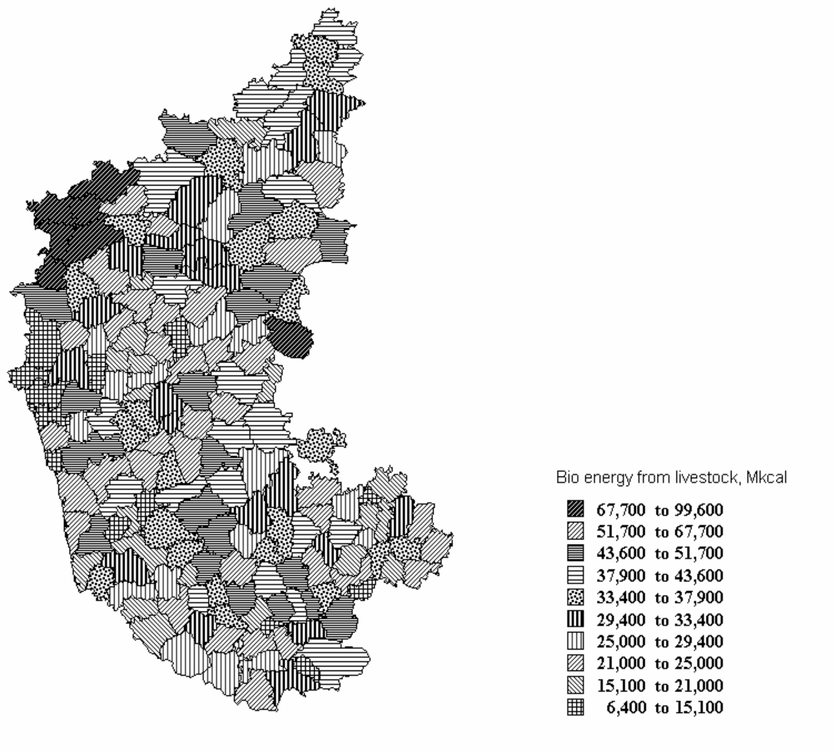

Fig. 6 Taluk wise distribution of bio energy from livestock

Computation of the total bio-resource available for energy show that Channagiri has highest bio-resource and source wise analysis show that horticultural residues (83.97%) and forests (13.65%) contribute a major percentage followed by agricultural residues (1.67%), animal residues (0.65%) and plantation (0.04%). Bio-resource availability is lowest in Anekal and the source wise analysis shows that horticulture residue (37.74%), livestock (28.54%) and agricultural residue (21.16%) contribute mainly for the energy production followed by forest residue (8.80%) and plantation (3.74%).

Bio-resource demand and status

The ratio of availability to demand indicates the bio-resource status of various taluks in the state. Ratio greater than one indicates the presence of surplus bio-resource, while a value less than one characterises a bio-resource deficient zone. Table 2 gives Taluk wise for Karnataka state the values of biomass availability, demand and status. Note: There are 175 taluks in Karnataka and Table 2 provides the bioenergy status of representative taluks where field sampling was carried out.

Fig. 7 illustrates bio-resource surplus and deficit zones in the state. The computation of bioenergy availability, demand and status talukwise shows that Siddapura (ACZ9) taluk in Uttara Kannada district has the highest bioenergy status of 2.004. Anekal (ACZ5) taluk in Bangalore Urban district has the least status of 0.004.

Table 2 Taluk wise status of bioenergy in Mkcal

District	Taluk	ACZ	Availability of Fuelwood	Demand	Bioenergy Status
Bangalore Urban	Anekal	5	28732.78	6007202	0.005
Bangalore Rural	Kanakapura	5	1131050.74	1723443	0.656
Belgaum	Athani	3	1642628.863	10278257	0.161
	Gokak	3	870640.68	9697864	0.094
Bellary	Bellary	3	239704.49	7480940	0.032
	Sandur	3	856768.41	3780317	0.227
Bidar	Aurad	1	168446.85	9262327	0.018
Bijapur	Basavanabagevadi	3	103433.7512	6709051	0.015
Bagalkote	Badami	3	974281.14	5182396	0.188
Chikmagalur	Chikmagalur	9	1727383.05	1353695	1.276
Chitradurga	Challekere	4	210461.77	196354.69	1.072
Davangere	Davangere	4	2136901.7	1811516	1.186
Dakshina Kannada	Mangalore	10	1374848.2	1028543	1.337
	Puthur	10	4806276.38	3709993	1.295
Udupi	Karkalla	10	3533849.99	3051057	1.158
Dharwad	Dharwad	8	75167.47	8310029	0.009
Gadag	Gadag	3	79722.83	3928923	0.020
Haveri	Hanagal	9	317206.92	281388	1.127
Gulbarga	Afzalpur	2	240821.733	3903886	0.062
Hassan	Alur	7	355159.4	334760	1.061
	Arakalagudu	7	1180177.69	982546	1.201
Kodagu	Madikeri	9	2076517.19	1833362	1.133
Kolar	Bagepalli	5	253877.386	3716958	0.068
	Chikballapur	5	258840.195	3205060	0.081
Mandya	K.r.pet	6	535224.3	5643175	0.095
Mysore	Hunasur	7	409928.87	289485	1.416
Chamrajnagar	Chamrajnagar	6	1385151.19	6937542	0.271
Raichur	Lingasur	3	310644.41	5913320	0.053
Koppal	Gangavathi	3	341951.74	7308312	0.047
Shimoga	Hosanagara	9	2859495.46	2195367	1.303
Tumkur	Chiknayakanhalli	4	1025581.6	4684893	0.219
Uttara Kannada	Ankola	10	2378579.27	1378801	1.725
	Bhatkal	10	1606241.01	1335545	1.203
	Honnavar	10	2966472.64	2347553	1.264
	Karwar	10	3298652.29	3286046	1.004
	Kumta	10	4615091.93	4004825	1.152
	Haliyal	9	2954292.81	2194837	1.346
	Mundgod	9	2101698.17	1956552	1.074
	Siddapura	9	2871496.5	1432836	2.004
	Sirsi	9	4337474.66	2897781	1.497
	Supa	9	1531984.8	1288548	1.189
	Yellapur	9	2371085.9	1958598	1.211

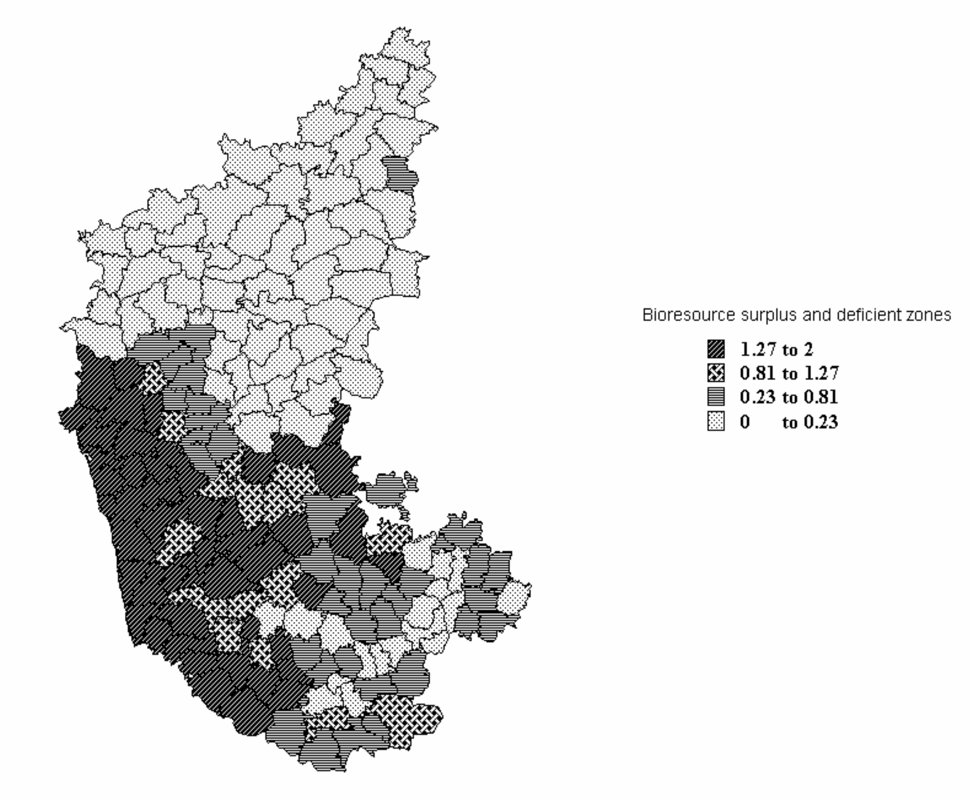

Fig. 7 Taluk wise distribution of bio-resource surplus and deficient zones

Conclusion

From the study it is evident that few taluks situated in Southern transition zone (ACZ7- covering parts of Hassan, Chikmagalur, Shimoga, Mysore and a small potion of Tumkur district), Hilly zone (ACZ9- covering parts of Uttara Kannada, Belgaum, Shimoga, Chikmagalur, Haveri, Kodagu and one taluk of Hassan), and Coastal zone (ACZ10- covering parts of Uttara Kannada, Udupi and Dakshina Kannada district) have surplus bio-resource. Analyses of sector wise contribution in the energy surplus zones shows that horticulture residues contribute in the central dry zone, southern transition zone and the coastal zone, while in the hilly zone, forests contribute more towards the available bioenergy.

In the southern transition zone, about 127769 ha of wasteland are available for energy plantation. The extent of wastelands in hilly and coastal zones, is about 237371 ha and 880189 ha respectively. This can be utilised for raising energy plantation comprising of Acacaia auriculiformis, Casuarina and Eucalyptus species. Assuming an average biomass productivity of 5t/ha/year, the total amount of exploitable biomass available from these plantations would be 4400945 tonnes annually. With the population increasing rapidly, the existing bio-resource can be sustained by using other energy alternatives like biogas.

Compared to these, taluks located in northeastern transition zone (ACZ 1), northern dry zone (ACZ 2), northeastern dry zone (ACZ 3), eastern dry zone (ACZ 5), southern dry zone (ACZ 6) and the northern transition zone (ACZ 8) are bio-resource deficient zones. In the northeastern transition zone, agriculture residues contribute 52% and forests 48% in meeting the energy demand. About 120305 ha of wastelands are available in this zone that could be used for energy plantations. In the northeastern dry zone, forests contribute 53% and agriculture 47% towards the rural energy demand. The extent of wastelands available in this zone is 325330 ha.

In the northern dry zone, agriculture contributes to 59%, forests 40% and horticulture 1% towards the total energy requirements. About 850998 ha of wastelands are available in this zone. In the eastern dry zone, horticulture contributes 53%, forests-39% and agro residues-8% towards the total energy requirements. About 228196 ha of wasteland are available in this region. In the southern dry zone, forests contribute 53%, while agriculture and horticulture residues contribute 28% and 19% respectively in meeting the bioenergy demand. 314755 ha of wastelands are available in this zone, capable of being used for energy plantations. In the northern transition zone, agriculture contributes 61%, forests 36% and horticulture residues 2% towards bioenergy demand. The extent of wastelands available in this zone is 99462 ha. The total extent of wastelands available for the energy deficient zones is 1999046 ha. Raising a mixed species energy plantation and assuming a productivity of 5t/ha/year, the total available biomass would be 9995230 tonnes annually.

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