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Spatial mapping of renewable energy potential

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Abstract

An energy resource that is renewed by nature and whose supply is not affected by the rate of consumption is often termed as renewable energy. The need to search for renewable, alternate and non-polluting sources of energy assumes top priority for self-reliance in the regional energy supply. This demands an estimation of available energy resources spatially to evolve better management strategies for ensuring sustainability of resources. The spatial mapping of availability and demand of energy resources would help in the integrated regional energy planning through an appropriate energy supply–demand matching. This paper discusses the application of Geographical Information System (GIS) to map the renewable energy potential talukwise in Karnataka State, India. Taluk is an administrative division in the federal set-up in India to implement developmental programmes like dissemination of biogas, improved stoves, etc. Hence, this paper focuses talukwise mapping of renewable energy (solar, wind, bioenergy and small hydroenergy) potential for Karnataka using GIS. GIS helps in spatial and temporal analyses of the resources and demand and also aids as Decision Support System while implementing location-specific renewable energy technologies.

Regions suitable for tapping solar energy are mapped based on global solar radiation data, which provides a picture of the potential. Coastal taluks in Uttara Kannada have higher global solar radiation during summer (6.31 kWh/m^2), monsoon (4.16 kWh/m^2) and winter (5.48 kWh/m^2). Mapping of regions suitable for tapping wind energy has been done based on wind velocity data, and it shows that Chikkodi taluk, Belgaum district, has higher potential during summer (6.06 m/s), monsoon (8.27 m/s) and winter (5.19 m/s). Mysore district has the maximum number of small hydropower plants with a capacity of 36 MW. Talukwise computation of bioenergy availability from

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agricultural residue, forest, horticulture, plantation and livestock indicates that Channagiri taluk in Shimoga district yields maximum bioenergy. The bioenergy status analysis shows that Siddapur taluk in Uttara Kannada district has the highest bioenergy status of 2.004 (ratio of bioresource availability and demand).

Keywords: Renewable energy; Spatial analysis; Solar energy; Wind energy; Hydroenergy; Bioenergy; Energy demand; Energy potential; Bioenergy status; GIS

Contents

1. Introduction

The threat posed to sustainability by greenhouse gas emissions and deterioration of the natural resource base (e.g., oil crisis, etc.) has caused worldwide concern. 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. The natural resource base has deteriorated considerably due to the rapid growth in population coupled with unplanned developmental activities including industrialisation and urbanisation. This also has resulted in exponential increase in fossil fuel consumption. Post-oil crises shifted the focus towards renewable resources and energy conservation. This would imply a shift to renewable energy sources from non-renewable fossil fuels, which ensures sustainability. Renewable energy resources are those having a cycling time less than 100 yr. These are the resources that are renewed by nature again and again, and their supply is not affected by the rate of consumption. Examples for renewable energy are solar, wind, hydroenergy, tidal, geothermal, biomass and energy from organic wastes such as biogas, etc. The consumption of energy for lighting, cooking, heating and other appliances by households and the service industry has shown a significant change in recent years. To understand the kind of resource used by different sectors of usage, it is important to review the energy use trends.

Coal is the predominant energy source (58%) in India, followed by oil (27%), natural gas (7%), lignite (4%), hydropower (3%) and nuclear power (0.22%). Energy consumption patterns in the Indian residential sector vary widely not only among the rural and urban areas but also across various income classes in urban areas. Approximately 86.1% rural households in India use fuel wood and dung cakes for cooking, 3.5% rural households use LPG for cooking, 50.6% of rural households use kerosene and 48.4% use electricity as a primary source of lighting. The annual average fuel wood consumption is around 270–300 million tonne, kerosene consumption is about 10.5 million tonne out of which 60% is in rural areas [1]. India's present energy scenario calls for the effective management of all available resources in order to attain national objectives. A well-balanced fuel mix, in which all energy resources are appropriately utilised, is essential for sustainable development. Renewable energy resources, which the country has in abundance, such as solar, wind, biomass, small hydroenergy, etc., can effectively meet energy demand and are environmentally benign. About 3700 MW of power-generating capacity based on renewable energy sources has been installed in the country so far. This constitutes about 3.5% of the total installed capacity [2]. Table 1 gives renewable energy potential and its achievement in India.

Energy utilisation in Karnataka considering all types of energy sources and sectorwise consumption revealed that traditional fuels such as firewood (7.440 million tonnes of oil equivalent—43.62%), agro residues (1.510 million tonnes of oil equivalent—8.85%), biogas and cowdung (0.250 million tonnes of oil equivalent—1.47%) account for 53.20% of the total energy consumption in Karnataka. In rural areas, the dependence on bioenergy to meet the domestic requirements such as cooking and water-heating purposes are as high as 80–85% [3].

Efficient use of energy is achieved when unnecessary energy conversions are avoided, as each conversion has limited efficiency and, therefore, implies a certain loss of energy as

Table 1
Renewable energy potential and achievement in India

Source/technologies	Approximate potential	Cumulative achievements (MW) (Up to 31.03.2003)	India's position in the world
Solar photovoltaic	20 MW/km^2	121.00	5th
Wind power	45,000 MW	1870.00	5th
Biomass-based power	19,500 MW	483.90	4th
Biogasifier	16,000 MW	53.40	1st
Small hydropower	15,000 MW	1509.24	10th

(MNES: http://mnes.nic.in/frame.htm?majorprog.htm).

wasted heat. For instance, if secondary energy can immediately serve as final energy or even as useful energy, substantial losses can be avoided, e.g., wind machines in irrigation or hydroturbines powering a shaft. This principle favours decentralised energy generation and is particularly relevant with new and renewable energy sources. Very high efficiencies can be achieved with cogeneration, where heat as a by-product of power is not wasted, but put to good use on the spot.

1.1. Solar energy

The Sun is by far the largest object in the solar system. It contains more than 99.8% of the total mass of the solar system. The Sun's energy output (3.86e33 erg/s or 386 billion MW) is produced by nuclear fusion reactions. Each second, about 700 million tonnes of hydrogen is converted to about 695 million tonnes of helium and 5 million tonnes (= 3.86e33 erg) of energy in the form of gamma rays. As it travels out towards the surface, the energy is continuously absorbed and re-emitted at lower and lower temperatures so that by the time it reaches the surface, it is primarily visible light. For the last 20% of the way to the surface, the energy is carried more by convection than by radiation [4]. From the Sun's surface, the radiation is then transferred to the whole of the solar system. An annual energy of 1.5×10^{18} kWh is obtained from the Sun to the earth. This is about 10,000 times larger than the current annual energy consumption of the world. The surface temperature of the Sun is around 5503.85 °C. Energy is continuously released from the Sun by a fusion reaction, which produces 3.94×10^{23} kW of power. Radiation from the Sun takes about $9\frac{1}{3}$ min to cover 93 million miles to the earth. The earth receives only a small fraction of the total power emitted by the Sun, an amount of 1.73×10^{14} kW or 340 W/m^2 averaged over the whole earth surface. Approximately 30% is reflected back to space and 20% is absorbed by clouds, dust and "greenhouse" gas such as water vapour, carbon dioxide and ozone. The annual global radiation in India varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6000 million GW h of energy per year [5].

The total quantity of short-wave radiant energy emitted by the Sun's disc, as well as that scattered diffusively by the atmosphere and cloud, passing through a unit area in the horizontal in unit time is referred generally as global solar radiation. Monitoring the daily global solar radiation will help in assessing the total solar energy at any location considering diurnal and seasonal variations. The global solar radiation reaching the earth's surface is made up of two components, direct and diffuse. The sum of the direct and diffuse components reaching a horizontal surface is global radiation. Direct radiation is the part which travels unimpeded through space and the atmosphere to the surface, and diffused radiation is the part scattered by atmospheric constituents such as molecules, aerosols and clouds. In simple terms, direct radiation causes shadows and diffuse radiation is responsible for skylight [6].

India receives solar energy equivalent to more than 5000 trillion kWh/yr, which is far more than its total annual energy consumption. The daily average global radiation is around 5 kWh/m^2 day with the sunshine hours ranging between 2300 and 3200 per year. Though the energy density is low and the availability is not continuous, it is now possible to harness this abundantly available energy very reliably for many purposes by converting it to usable heat or through direct generation of electricity. The total solar photovoltaic (PV) capacity in India is 2490 kW. A large number of solar water heaters with the collector area of about 30,000 m^2 have been financed till December 2002. A total collector area of 6,80,000 m^2 has been installed in the country so far. During the year 2002–2003, over 5000 box solar cookers were sold till 31.12.2002 making a total of 5,30,000 cookers sold in the country till date [2].

1.1.1. Global solar radiation

Computation of daily sums of global solar radiation at sites where no radiation data are available can be done through various probable relationships among the parameters such as (i) sunshine and cloudiness and (ii) extra terrestrial radiation allowing for its depletion by absorption and scattering in the atmosphere [7]. There is a relationship between solar radiation received on earth's surface and sunshine [8]. Relation of global solar radiation is obtained by considering the influence of climatological multivariates like mean temperature (T_m), relative humidity (RH), specific humidity (SH) as follows:

$$G'/\mathrm{ETR} = f_1 + f_2(n/N') + f_3 T_m + f_4 \mathrm{SH}. \tag{1}$$

SH is used instead of RH to take care of the relatively large variation in RH and is given by

$$\mathrm{SH} = \mathrm{RH}(4.7923 + 0.3647\,T_m + 0.55\,T_m^2 + 0.0003\,T_m^3), \tag{2}$$

where RH as mentioned above is the relative humidity, f_1,f_2,f_3 and f_4 are empirical constants, which vary with geographical location.

1.2. Wind energy

Wind energy is another form of solar energy. Sunlight falling on the ocean and continents causes air to warm and rise, which in turn generates surface winds. Wind is affected significantly by topography, weather conditions with seasonal, daily and hourly variation, and land use pattern. The total annual kinetic energy of air movement in the atmosphere is estimated to be around 3×10^6 TWh or about 0.2% of solar energy reaching the earth [9]. Windmills are used to harness wind energy. The power of wind blowing at 25.6 km/h is about 200 W/m^2 of the area swept by windmill. Approximately 35% of this power can be captured by the windmill and converted to electricity. Maximum amount of wind energy can be harnessed only in windy locations like on mountaintops and coasts. Such places are suitable for the economic generation of electricity by wind power.

According to initial estimates, India's wind power potential was assessed at around 20,000 MW. It has been re-assessed at 45,000 MW, assuming 1% of land availability for wind power generation in potential areas. However, the present exploitable technical potential is limited to 13,000 MW, on account of the limitation of grid capacity in the State Grids. Grid penetration of more than 20% could result in grid instability. The technical potential will go up with the augmentation of grid capacity in the potential States. Karnataka has a gross potential of 6620 MW and technical potential of 1120 MW [2].

1.2.1. Wind speed

The annual wind speed at a location is useful as an initial indicator of the value of wind energy potential. This can be extrapolated by the following equation:

$$v = v_0[h/h_0]^k, \tag{3}$$

Table 2
Annual mean wind speed and potential value of the wind energy resource

Annual mean wind speed at 10 m ht	Indicated value of wind resource
< 4.5 m/s	Poor
4.5–5.4 m/s	Marginal
5.4–6.7 m/s	Good to very good
>6.7 m/s	Exceptional

where v is the wind speed at height h in m/s, v_o the wind speed at anemometer height h_o in m/s, h the height at which wind speed is measured in m, h_o the anemometer height (usually 10 m) and k the height exponent (0.14–0.3).

The relationship between the annual mean wind speed and the potential value of the wind energy resource as considered in India [10] is listed in Table 2.

Energy pattern factor (EPF) and power densities are computed for sites with hourly wind data. With the knowledge of EPF and mean wind speed, mean power density is computed for the locations with only hourly and monthly data. The wind power density (P) or energy flux or the power per unit area normal to the wind is expressed in W/m^2. Wind power density of a stream of air with density d moving with a velocity v_m is given by

$$P = K_{\mathrm{Em}} \mathrm{d} v_{\mathrm{m}}^3/2, \tag{4}$$

where $K_{\mathrm{Em}} = \mathrm{EPF}$,

$$K_{\mathrm{Em}} = \left(\sum v_i^3/N_{\mathrm{m}}\right)/v_{\mathrm{m}}^3, \tag{5}$$

where v_i is the hourly wind speed during the month, N_{m} the number of hourly wind speed values during the month and v_{m} the monthly mean wind speed.

1.3. Hydroenergy

Hydropower owes its position as a renewable resource, as it depends ultimately on the natural evaporation of water by solar energy and precipitation. Hydropower, large or small, remains by far the most important of the "renewables" for electrical power production worldwide, providing 19% of the planet's electricity. The exploitable hydroresources in the world are enormous and the total estimated hydroelectric resources in the world are 2,261,000 MW [11]. The power available is proportional to the rate of discharge of the water and is given by

$$P = 1000\, gHQ\eta, \tag{6}$$

where 1000 is the mass of water in kg/m^3, g the acceleration due to gravity in m/s^2, η the hydraulic efficiency of the turbine expressed as fraction, H the effective head of water in m and Q the flow rate passing through the turbine in m^3/s.

Hydroelectric power plants are generally located near dams or river barrages. The capacity of hydropower plants can vary between a few kW and thousands of kW. Depending on this, hydropower plants are classified as micro (up to 100 kW), mini (up to 3 MW) and small (up to 25 MW) plants. The small hydropower plant (SHP), i.e., up to 25 MW capacity, is set to attain commercial status in the country. SHP projects are becoming economically viable with appropriate systems for evacuation/utilisation of power from the project being increasingly put in place. In India, over 4215 SHP sites have been identified with a total capacity of 10,279 MW. India has an estimated SHP potential of about 15,000 MW; 453 SHP projects with an aggregate installed capacity of 1,463 MW have been installed. Besides, 199 SHP projects with an installed capacity of 538 MW are being commissioned. A database has been created for potential sites suitable for SHP projects [2].

The Karnataka State government has so far accorded permission to private developers to establish small hydroprojects in more than 79 locations amounting to 465 MW. Private developers have commissioned eight projects with an installed capacity of 49 MW. Over the next 2 yr, 20 projects with a capacity of 150 MW are expected to be commissioned. More than 450 million units of electrical energy have been generated from the eight small hydroprojects commissioned in the State [12].

1.4. Bioenergy

Biomass refers to the organic matter derived from biological organisms (plants, animals, algae). They are basically classified into two categories:

- Biomass from cultivated field, crops and forests (dead wood, twigs, litter, etc.).
- Biomass derived from wastes like municipal wastes, animal residues/dung, forest and agricultural wastes, bioprocess wastes, etc.

Biomass energy is a result of solar energy converted to biomass energy by green plants. Only green plants are capable of photosynthesis. As per an estimate, photosynthesis produces 220 billion dry tonnes of biomass per year globally, with 1% conversion efficiency [11].

The total bioenergy potential in India is about 19,500 MW, including 3500 MW of exportable surplus power from bagasse-based cogeneration in sugar mills and 16,000 MW of grid quality power from other biomass resources. The total installed capacity in the country, as of December 31, 2002, is 468 MW and projects of capacity 530 MW are in various stages of implementation. Biomass gasifier of total capacity 55.105 MW has so far been installed, mainly for stand-alone applications [2].

Quality of life in rural areas can be improved through the efficient use of locally available bioenergy sources by recovering the energy from cattle dung, human waste and non-woody organic wastes without losing their manurial value through biogas plants. Against an estimated potential of 12 million biogas plants, about 3.44 million family type plants have been set up so far, representing coverage of over 28% of the potential. In addition, about 4000 night soil-based and institutional biogas plants have been set up. Monitoring of these plants by the regional offices of the Ministry of Non-Conventional Energy Sources (MNES) shows an overall functionality of 86%. These plants have helped to save 44 lakh tonnes of fuelwood, produced 450 lakh tonnes of manure per year. An estimated 4.5 million people per day of employment has also been generated in the rural areas. Research and development efforts are being taken up to develop new designs and improve the efficiency of biogas plants in different geographical and climatic conditions [2].

2. Literature reviews

Chang et al. [13] review the production and consumption of traditional and renewable energy in China over the past three decades, and present an overview on the research and development of renewable energy in China. The study indicated that the renewable energy in China shows a promising prospect, of which biomass is found to be one of the most promising renewable energy resources with great potential for development. Since 1993, the output of domestic crystalline silicon solar cells soared by 20–30% annually; the total installed capacity of PV systems in China was approximately 22 MW at the end of 2002. Seven tidal power stations and one tide flood power station are in operation with a total capacity of 11 MW in China. Almost 20% of the primary energy consumed in China is biomass energy.

Evrendilek and Ertekin [14] assessed the potential of renewable energy sources in Turkey to meet the growing energy demand. Turkey's limited amount of fossil fuels has a present average ratio of proved reserves of 97.38 quads to production rate of 3.2 quads/yr for about 30 yr. Economically feasible renewable energy potential in Turkey is estimated at a total of 1.69 quads/yr (495.4 TWh/yr) with the potential for 0.67 quads/yr (196.7 TWh/yr) of biomass energy, 0.42 quads/yr (124 TWh/yr) of hydropower, 0.35 quads/yr (102.3 TWh/yr) of solar energy, 0.17 quads/yr (50 TWh/yr) of wind energy and 0.08 quads/yr (22.4 TWh/yr) of geothermal energy. Pursuit and implementation of sustainability-based energy policy could provide about 90% and 35% of Turkey's total energy supply and consumption projected in 2010, respectively. Utilisation of renewable energy technologies for electricity generation would necessitate about 23.2 Mha (29.8%) of Turkey's land resources.

Krewitt and Nitsch [15] developed a geographical information system (GIS)-based approach to analyse the effect of different nature conservation criteria on the wind energy potential in quantitative terms. The wind energy potential feasibility is demonstrated by quantifying the potential while taking into account detailed site-specific information on nature conservation aspects. Wind energy potential amounts to only 25% of the theoretical potential. Ban on wind energy in areas of medium-to-high visual sensitivity in the Baden-Württemberg case study area reduces the wind potential by a further 20%. Results for two case-study regions in Germany, representing a coastal area with a high wind potential (the state of Lower Saxony) and an inland region with limited wind potential (the state of Baden-Württemberg), suggest that the potential for electricity generation from wind energy even under strict nature conservation constraints in these regions amounts to about 35 TWh/yr, which is considered as a lower estimate of the actual potential.

Serwan et al. [16] have adopted GIS to locate wind farms in UK. In terms of area, as would be expected, the most suitable areas represent the smallest group, occupying only 3.79% of the total study area while the least suitable sites cover some 73.34% of the area. The suitability map using weighted layers showed a very similar pattern. However, the analysis in terms of areas occupied by each suitability class shows that these have changed slightly in favour of the most suitable sites. The most suitable areas are occupying 8.32% of the total study area while the least suitable sites cover 70.26% of the area.

Rylatt et al. [17] describe the development of a solar energy planning system, consisting of a methodology and decision support system for planners and energy advisers. The study primarily intends to predict and realise the potential of solar energy on an urban scale, and the system will support decisions in relation to the key solar technologies: solar water heating, PV and passive solar gain. The prototype discussed here relates to the first of these. Based on a methodology for predicting the solar energy potential of domestic housing stock, it is implemented as a relational database application linked to a customised GIS. The methodology takes into account baseline energy consumption and projected energy saving benefits. To support this, the system incorporates a domestic energy model and addresses the major problem of data collection in two ways. Firstly, it provides a comprehensive set of default values derived from a new dwelling classification scheme that builds on previous research. Secondly, novel GIS tools enable key data to be extracted from digital urban maps in different operational modes.

Bent Sorensen [18] employs GIS to map solar resources on the basis of satellite data (radiation at top of the atmosphere, albedo, downward radiation at surface) and to match it with demand modelling on a habitat basis (population density, energy demand intensity). PV potential use is based on estimates of practical areas for collection use (building roof areas, suitably inclined and oriented surfaces) combined with land use data (important for central receiver fields). Local measurement data have been converted to the GIS grid employed. For the centralised PV system, the estimated potential is taken as 15% of radiation times the fraction of the two area types (1% of all rangeland and 5% of all marginal land (deserts and scrubland)) and a factor of 0.75 in order to account for transmission and storage cycle.

Nandalal and Sakthivadivel [19] investigated the operational behaviour of Samanalawewa and Udawalawe reservoirs. The model ShellDP was used to study the performance of the Samanalawewa and Udawalawe reservoirs. The model used in the study is based on stochastic dynamic programming (SDP) and simulation techniques. Since, the direct application of SDP for two reservoirs was limited by the dimensionality of the problem, a sequential decomposition method was employed in the model. The results showed an evaporation loss of $9.6 \times 10^6\,m^3$, the water released from the reservoir was $533.89 \times 10^6\,m^3$, spillage was $3.3 \times 10^6\,m^3$ and the power generated was 334.9 GW h for Samanalawewa reservoir; for the Udawalawe reservoir, the results showed an evaporation loss of $34.6 \times 10^6\,m^3$, the water released from the reservoir was $858.5 \times 10^6\,m^3$, spillage was $19.7 \times 10^6\,m^3$ and the power generated was 13.6 GW h.

Ramachandra et al. [20] computed the hydropotential of the streams of Bedthi and Aghnashini river basins in Uttara Kannada district of Western Ghats. Potentials at feasible sites are assessed based on stream gauging carried out for a period of 18 months. Computations of discharge on empirical/rational method based on 90 yr of precipitation data and the subsequent power and energy values computed are in conformity with the power calculations based on stream gauging. Their study has explored the possibility of harnessing hydropotential in an ecologically sound way to suit the requirements of the region. Energy that could be harnessed monthly is computed for all ungauged streams in the Bedthi and Aghnashini river catchments based on the empirical or rational method considering the precipitation history of the last 100 yr. The hydroenergy potentials of streams in the Bedthi and Aghnashini river catchments are estimated to be about 720 and 510 million kWh, respectively. The net energy computed for various dam heights indicates that dams of 67 m height store enough water to meet the region's lean season electricity requirements, and the area saved has a bioresource potential of 319 million units, which can cater the thermal energy demand of 312 million units. The cost per unit for various designs of the dam shows a 40.5% reduction in cost for a dam height reduction of 32.75%.

3. Objective

The main objectives of this study are:

- to assess spatially the availability of renewable energy resources,
- assessment of energy demand in each taluk and
- computation of bioenergy status (talukwise).

4. Study area

The study was carried out for Karnataka State in India, based on the data compiled for various locations. Karnataka is confined roughly within latitudes 11°31′N and 18°45′N and longitudes 74°12′E and 78°40′E and lies in the western central part of peninsular India (given in Fig. 1). It is situated on a tableland where the Western and Eastern Ghat ranges converge into the Nilgiri hill complex. Karnataka's total land area is 19.1 Mha, which

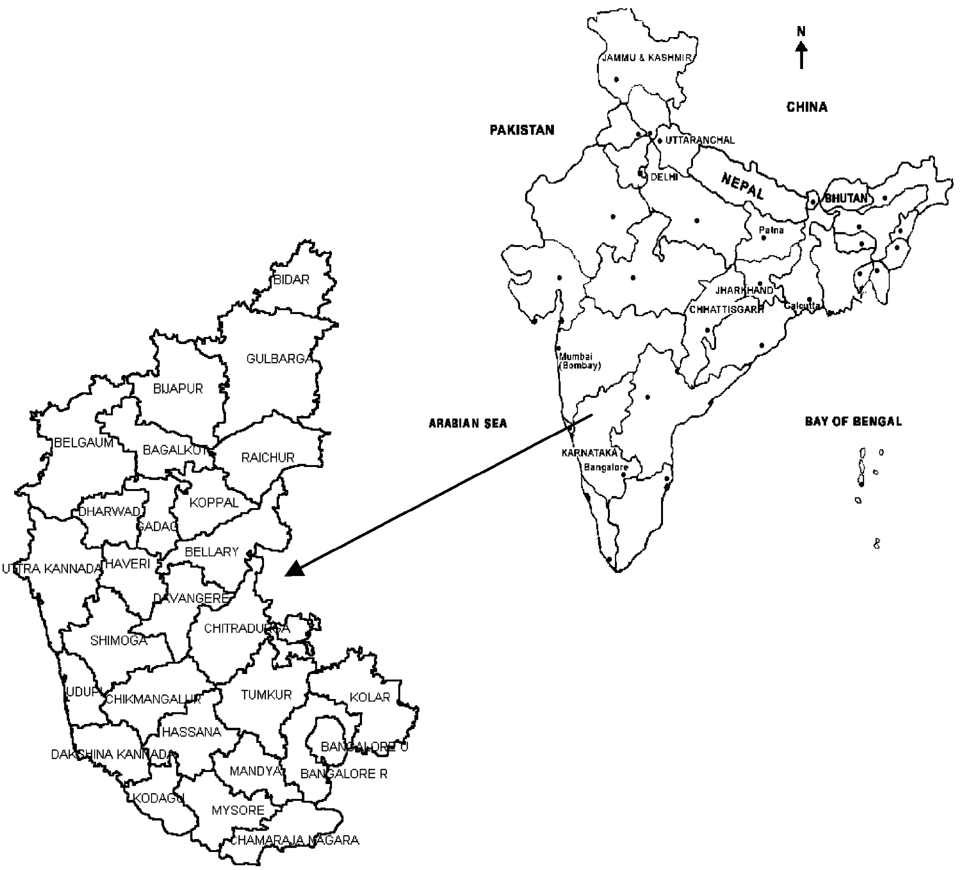

Fig. 1. Study area.

accounts for 5.35% of the total area of the country. For administrative purpose, the State is divided into 27 districts, which are sub-divided into 175 taluks.

5. Methodology

5.1. Solar energy

Stations where measurements of global solar radiation were available were used directly and for locations where the data was not available, indirect methods were used. They are as follows.

- From extra-terrestrial radiation, allowing for its depletion by absorption and scattering by atmospheric gases, dusts, aerosols and clouds. This is theoretically based and requires some approximation of the absorbing and the scattering property of the atmosphere.
- From other meteorological elements, such as duration of sunshine and cloudiness using regression technique. This method is empirical based, and the form usually used involves actual and potential hours of sunshine, which gives the regression constants for global and diffused solar radiation at the particular location or site.

The average monthly global solar radiation is calculated using Eq. (1). Based on the R^2 value and the least value of standard error of the y estimate, empirical formula consisting of SH and mean temperature is the best relationship compared to others,

$$G'/\mathrm{ETR} = f_1 + f_2(n/N') + f_3 T_\mathrm{m} + f_4\mathrm{SH},$$

where T_m is the mean temperature and SH is the specific humidity.

The resulting global solar radiation is further classified based on seasons as summer (February–May), monsoon (June–September) and winter (October–January). Thematic maps are generated using GIS to assess the variability in global solar radiation. These maps will help in identifying the potential sites for harnessing solar energy.

5.2. Wind energy

Wind energy potential is calculated based on the wind data (annual average wind speed). Annual average wind velocity data for 29 wind-monitoring stations in Karnataka were collected from the India Meteorological Department (IMD), Government of India, Pune.

To analyse variations across seasons, data was grouped seasonwise as summer (February–May), monsoon (June–September) and winter (October–January). Seasonwise wind velocity and standard deviation were computed for 29 wind-monitoring stations. GIS is used for mapping wind resources spatially and to quantify and analyse temporal changes. Based on these, GIS thematic layers were generated, which would help in assessing the variability. The map helps to identify the most and the least suitable potential areas for harnessing wind energy.

5.3. Hydroenergy

Districtwise distribution of SHPs and their capacity were collected from Karnataka Renewable Energy Development Limited (KREDL). These data were then implemented in GIS to obtain districtwise hydroenergy variation considering SHPs.

5.4. Bioenergy

Bioenergy potential assessment is based on compilation and computation of bioresource supply for the energy generation. Bioresource supply from agricultural residue, forest, horticulture residue, plantation and livestock dung are considered to assess the energy potential talukwise. The data required for this purpose were collected from the State agencies such as Agriculture, Horticulture, Forest and Veterinary departments. These values were implemented in GIS to generate talukwise bioenergy availability maps. The talukwise 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.

6. Results

GIS is used for identifying and quantifying the effect of local constraints on the renewable energy potential. This helped in providing the flexibility to enrich the database, with spatial data on which decisions are based. This will provide additional renewable energy availability restriction considering spatial parameters.

6.1. Solar energy potential in Karnataka

Karnataka receives global solar radiation in the range of 5.1–6.4 kWh/m^2 during summer, 3.5–5.3 kWh/m^2 during monsoon and 3.8–5.9 kWh/m^2 during winter. The potential analysis reveals that maximum global solar radiation is in districts such as Uttara Kannada, Dakshina Kannada, etc. The study identifies that coastal parts of Karnataka with higher global solar radiation are ideally suited for harvesting solar energy.

Global solar radiation in Uttara Kannada during summer, monsoon and winter is 6.31, 4.16 and 5.48 kWh/m^2, respectively. Similarly, Dakshina Kannada has 6.16, 3.89 and 5.21 kWh/m^2 during summer, monsoon and winter, while Mandya district has minimum global solar radiation of 5.41, 3.45 and 3.73 kWh/m^2 during summer, monsoon and winter, respectively. The results were implemented in GIS to obtain maps showing districtwise variation of global solar radiation. Fig. 2 shows the districtwise variation of global solar radiation during summer, Fig. 3 during monsoon and Fig. 4 during winter.

6.2. Wind energy potential in Karnataka

Wind potential maps across various seasons were generated using GIS considering seasonal wind velocities at various locations. Wind velocities are presented as thematic

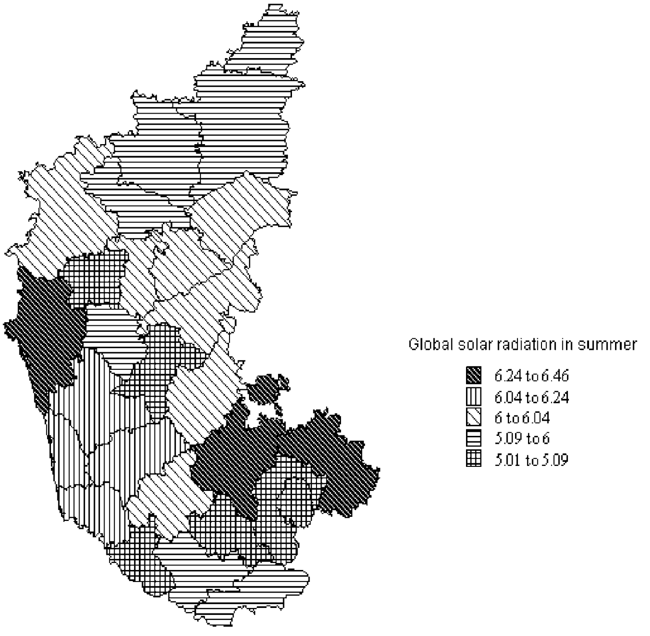

Fig. 2. Global solar radiations during summer.

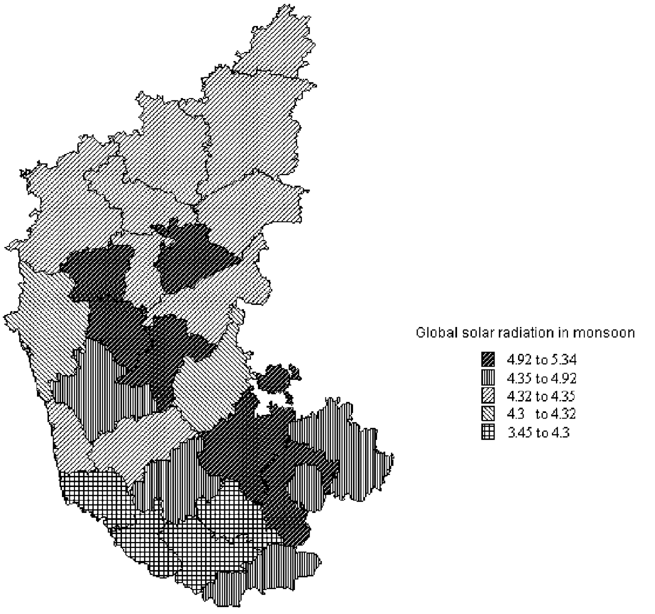

Fig. 3. Global solar radiations during monsoon.

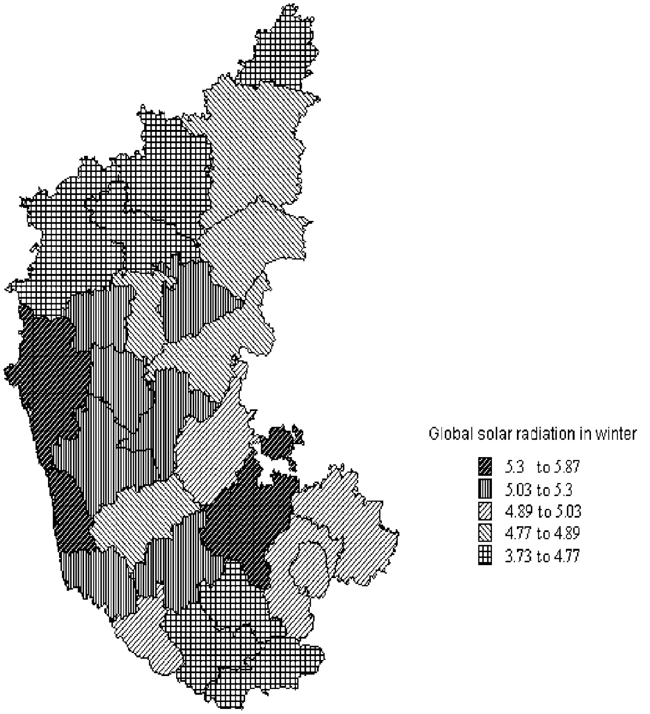

Fig. 4. Global solar radiations during winter.

layers, which help in identifying the sites with higher energy production. Figs. 5–7 depict the wind potential variability across seasons (summer, monsoon and winter) and across districts in Karnataka State, India. The wind potential is evaluated stationwise and is represented by a polygon in the map. A polygon corresponds to a district, which is an administrative unit in India to implement wind energy programmes at disaggregated levels. The map also shows the number of wind-monitoring stations. Chikkodi in Belgaum has the highest wind velocity.

Wind velocity in Chikkodi taluk, Belgaum district, during summer, monsoon and winter are 6.06, 8.27 and 5.19 m/s, respectively, while Bagalkote district has lowest wind velocity (0.52, 0.85 and 0.33 m/s during summer, monsoon and winter, respectively).

6.3. Hydropower in Karnataka

The total capacity of SHPs present in Karnataka is 164.74 MW. Mysore district has the maximum number of SHPs with a capacity of 36 MW. Fig. 8 illustrates the location of SHPs with their capacities. Karnataka Power Corporation Limited (KPCL) collected valuable data on flow discharges of some of the major rivers and streams in the State. It has established the availability of about 700 MW of small hydropotential in more than 166 locations in the State.

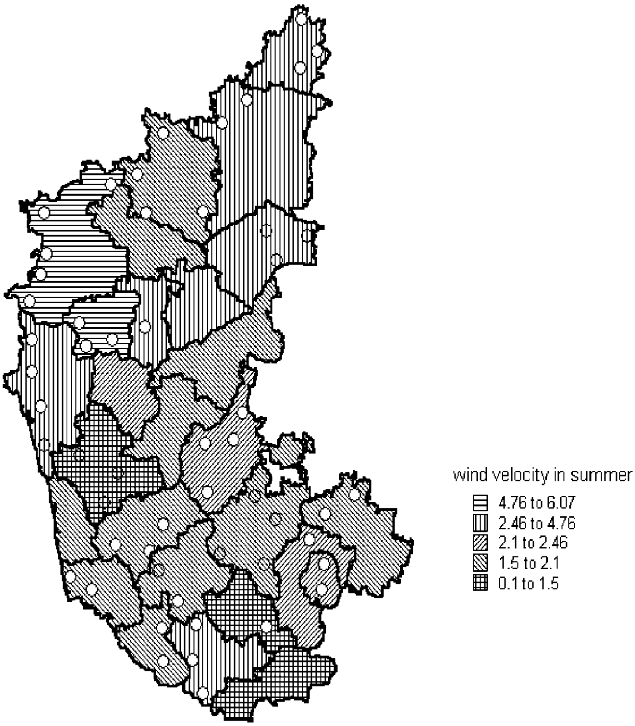

Fig. 5. Wind velocity during summer (m/s).

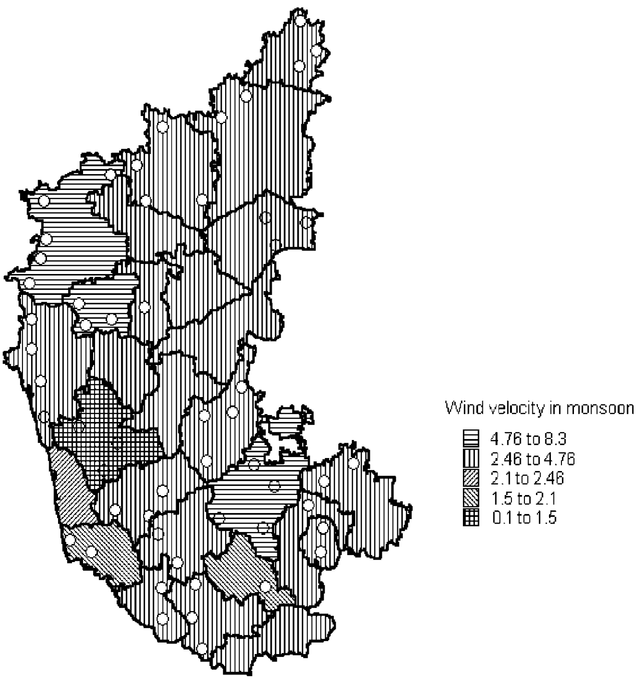

Fig. 6. Wind velocity during monsoon (m/s).

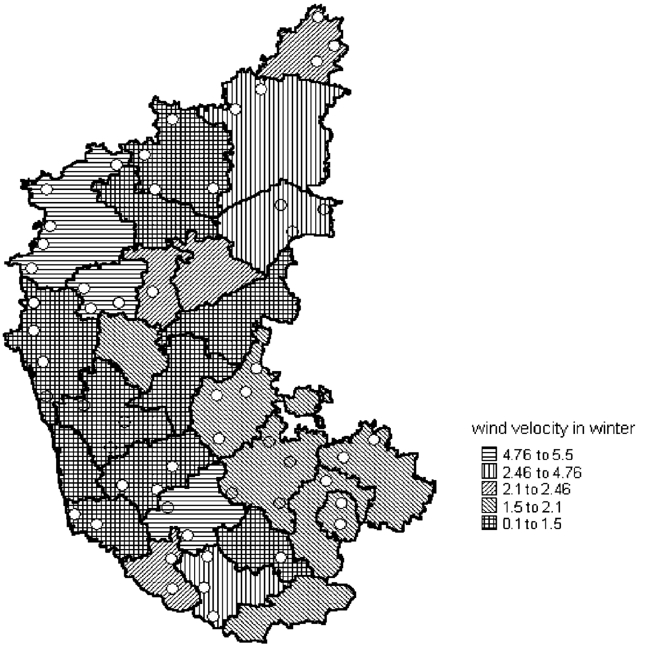

Fig. 7. Wind velocity during winter (m/s).

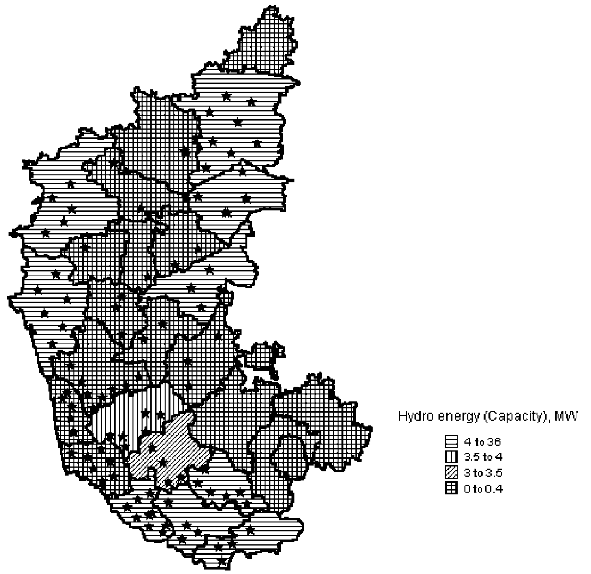

Fig. 8. Location of small hydropower plants with its capacities.

6.4. Bioenergy in Karnataka

The study reveals that maximum energy derived from bioresource is in Channagiri taluk (8,990,963 Mkcal) Davangere district, where agricultural residue constitutes 1.67% of the total bioresource, 13.65% from forest residue, 83.97% from horticulture residue, 0.04% from plantation and 0.65% from livestock. Anekal taluk in Bangalore Urban district derives minimum energy from bioresource (40,210.28 Mkcal). Agricultural residue constitutes 21.16% of the total bioresource, 8.80% from forest residue, 37.74% from horticulture residue, 3.74% from plantation and 28.54% from livestock. Talukwise computation of bioenergy availability from plant residue (agriculture, forest, horticulture and plantation) is illustrated in Fig. 9. Fig. 10 shows the bioenergy availability from animal residue (livestock). Fig. 11 illustrates the energy derived from total biomass (from plant residue and livestock).

6.5. Bioresource demand and status

Bioresource potential (from forests, plantations, agriculture, horticulture and animal residues) and demand, talukwise for Karnataka was calculated. The ratio of availability to demand indicates the bioresource status of various taluks in the State. Ratio greater than 1 indicates the presence of surplus bioresource, while a value less than 1 characterises a bioresource-deficient zone. When this ratio is less than 1, bioresources become non-renewable energy sources as there is scarcity of resources. The computation of bioenergy availability, demand and bioresources status talukwise shows that Siddapur taluk in Uttara Kannada district has the highest bioenergy status of 2.004. Anekal taluk in Bangalore Urban district has the least status of 0.004. Fig. 12 shows talukwise bioresource status of Karnataka.

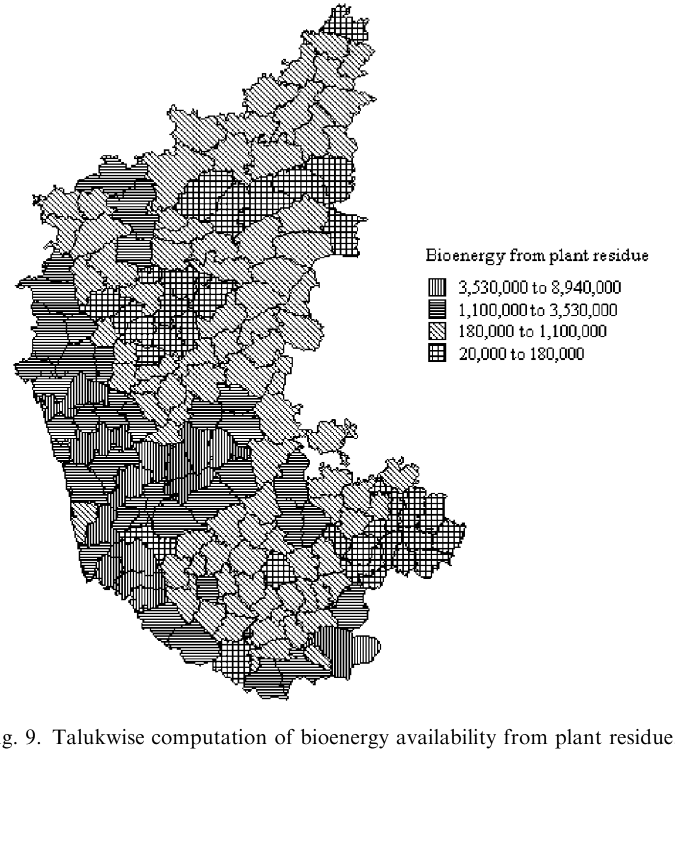

Fig. 9. Talukwise computation of bioenergy availability from plant residue.

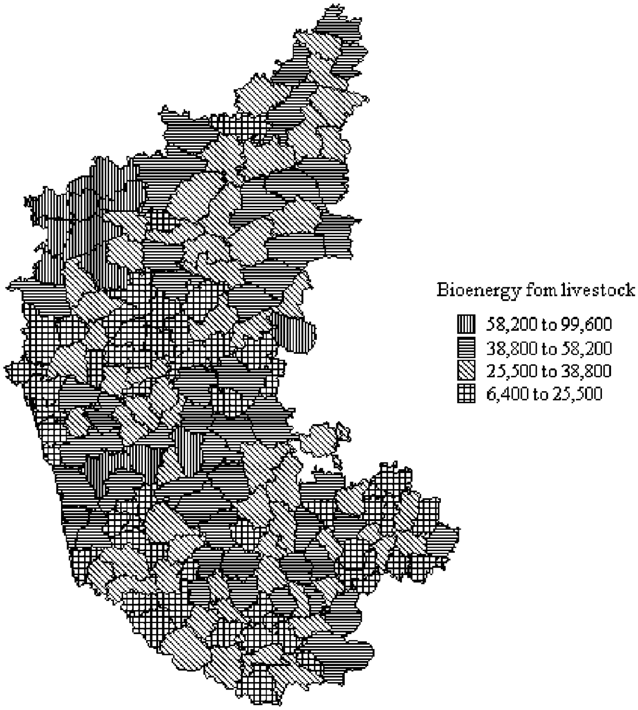

Fig. 10. Talukwise computation of bioenergy availability from livestock.

7. Conclusions

Solar energy is a clean, pollution free and renewable source of energy. Development of this source of energy requires an accurate detailed long-term knowledge of the potential taking into account seasonal variations. The region of the earth between the latitudes of 40°N and 40°S is generally known as the solar belt and this region is supposed to be with an abundant amount of solar radiation. Karnataka being located between latitudes 11°40′N and 18°27′N has a geographic position that favours the harvesting and development of solar energy. Karnataka receives global solar radiation in the range of 3.8–6.4 kWh/m^2. Global solar radiation during monsoon is less compared to summer and winter because of the dense cloud cover. The study identifies that coastal parts of Karnataka with the higher global solar radiation are ideally suited for harvesting solar energy.

Wind speed less than 5 m/s is not of much relevance to wind energy applications. Chikkodi, Horti, Kahanderayanahalli, Kamkarhatti, Raichur and Bidar have wind velocity greater than 5 m/s during most of the months, i.e., wind energy potential is high in these locations. Hence, these locations are recommended for construction of wind farms.

Small hydropower development is one of the thrust areas of power generation from renewables in the Ministry of Non-conventional Energy Sources (MNES). Ministry of Non-conventional Energy Sources is encouraging development of small hydroprojects in the State sector as well as through private sector participation in various States. The potential sources of small hydropower are at the base of existing irrigation dams, anicuts,

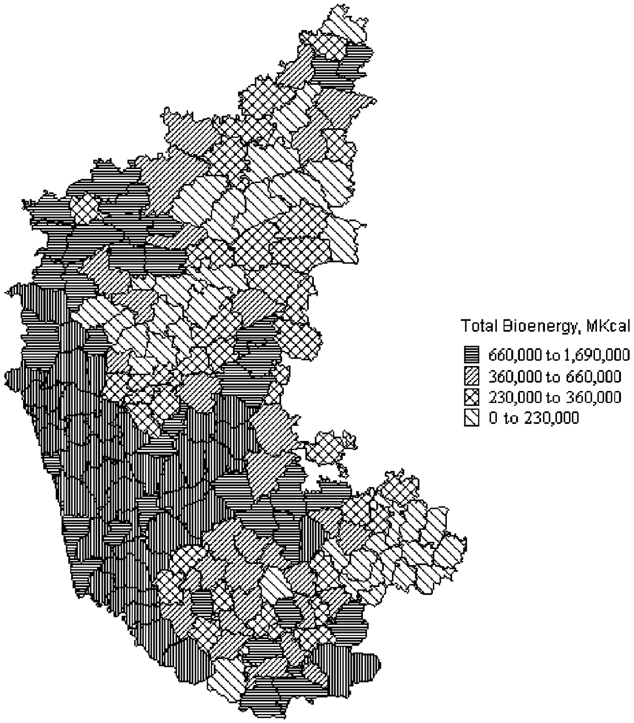

Fig. 11. Energy derived from total biomass (from plant residue and livestock).

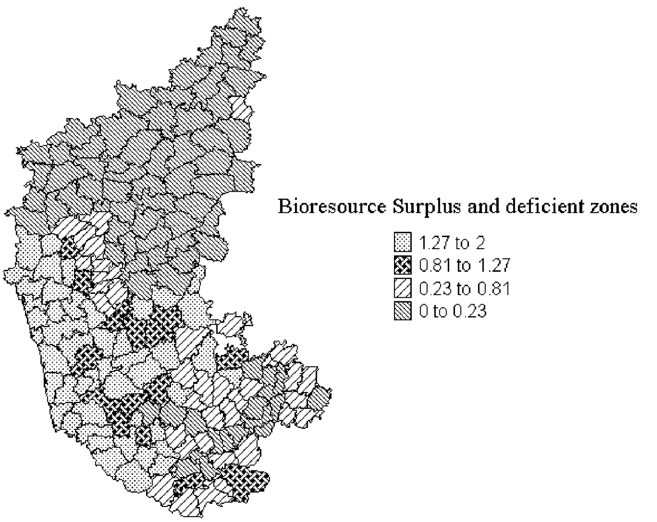

Fig. 12. Talukwise bioenergy status.

canal drops and hill streams. The State government has so far accorded permission to private developers to establish small hydroprojects in more than 79 locations amounting to 465 MW.

Resourcewise analysis of the study area reveals that bioresource from horticulture constitutes the major share of 43.6%, forest 39.8%, agriculture 13.3%, livestock 3.01% and plantation15%. The availability of bioresources in different taluks depends on the agroclimatic zones.

This study has demonstrated the role of spatial and temporal analysis tools such as GIS in assessing the resource potential in a region. GIS provided the means for identifying and quantifying the spatial and climatic factors affecting the availability of renewable energy potential. In addition to this, it also provided the flexibility to enrich the database, on which decisions are based, with spatial data and additional restriction on renewable resource availability.

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