Sustainable Energy Alternatives for Uttara Kannada

Ramachandra T.V. | **Subash Chandran M.D** | **Joshi N.V.**
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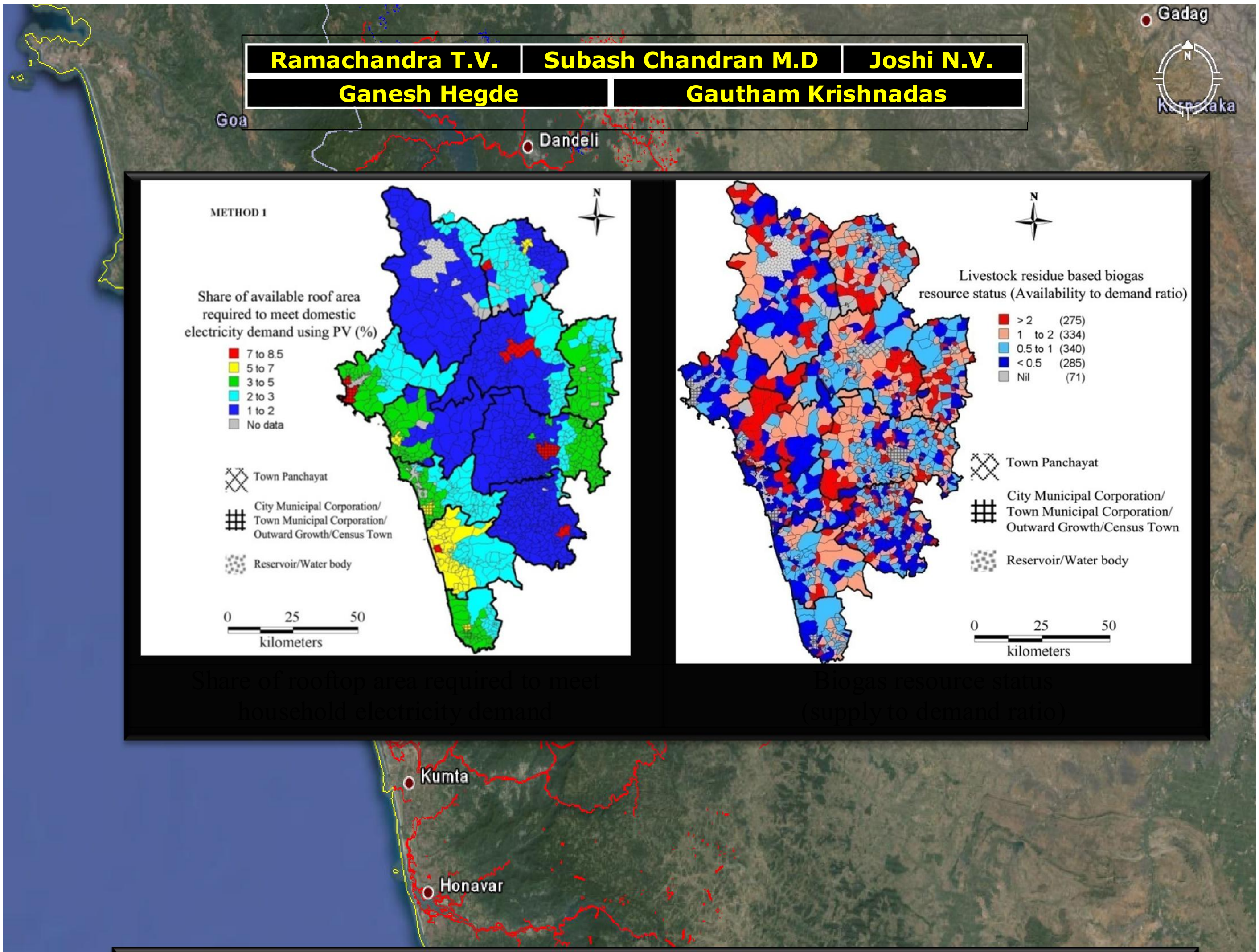

Share of rooftop area required to meet household electricity demand

Biogas resource status (supply to demand ratio)

Western Ghats Task Force, Government of Karnataka
Karnataka Biodiversity Board, Government of Karnataka
The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forests, Government of India

ENVIS Technical Report: 58

June 2013

Environmental Information System [ENVIS]
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Scope of Solar Energy in Uttara Kannada, Karnataka State, India: Roof top PV for domestic electricity and Standalone systems for irrigation

ABSTRACT

Energy is essential for economic and social development of a region. Dependence on fossil fuels has posed a serious threat due to greenhouse gas (GHG) emissions, dwindling stock of the fuel resource base. Among daily activities, about 80% of the mechanical work requires electrical energy. Dependence on the conventional energy resources for electricity generation is eroding the resources at faster rate. The process of electricity generation causes significant adverse effect on ecology by producing enormous quantity of byproducts including nuclear waste and carbon dioxide. Improving energy efficiency, switch over to renewable sources of energy and de-linking economic development from energy consumption (particularly of fossil fuels) is essential for sustainable development of a region. Green energy technologies have gained importance so that they are reliable and environmental friendly. Electrical energy harvesting from solar radiations is one such promising technology which uses photoelectric effect. Solar photovoltaic (SPV) modules directly convert solar radiations to direct current (DC) electrical power which can be used for various applications (or stored in battery) or can be sent to the existing grid. Uttara Kannada is located in the west coast of Karnataka, India, receives an average solar insolation of 5.42 kWh/m^2/day annually and has more than 300 clear sunny days. This solar potential can be utilized to meet the domestic and irrigation electricity demand. Domestic demand of the household in rural region is about 50 to 100 kWh per month and that in urban region is less than 150 kWh/month in Uttara Kannada. The solar potential assessment reveals that, domestic demand can be supplied by installing rooftop SPV modules, since less the 5% of the rooftop is required in majority of the houses and irrigation demand can be met by installing PV modules in wasteland where less than 3% of available wasteland area is sufficient. To estimate the fraction of rooftop required to generate sufficient electricity, rooftop area of a household in selected villages (chosen randomly, representative of agro-climatic zones) is digitized using Google earth image (http://googleearth.com). Electricity demand in households is estimated based on the sample household survey of 1700 households, which indicate the requirement of 50-100 units (kWh) per month per household. Computed rooftop area per household is used to extrapolate for all the villages in the district. Rooftop area required to install the PV module to meet the respective household's electricity demand is computed. The roof area required is less than 5% to meet the domestic demand of the respective household using rooftop PV system. In the similar manner the area required to generate electrical energy to meet the irrigation demand in the village is determined. In most of the villages in the district, less than 0.5% of the available wasteland is sufficient to meet the irrigation demand.

KEY WORDS: Insolation, Solar Photovoltaic (SPV), Rooftop PV module, domestic demand, sustainable energy.

1. INTRODUCTION

Electricity is a very good energy carrier which can be converted to any other form of energy and hence the demand is increasing in a higher rate (Ramachandra, 2011a, P: 176). Generation of electricity in India is mainly dependent on fossil fuels (fossil fuels: 78%, Hydro: 22%) in which coal is the predominant source (54%) (Planning Commission, Government of India, 2011, P: 4). Dependency on fossil based energy sources is resulting in fast depletion of non-renewable energy sources, apart from the problem of pollution, GHG emission, land transformation, deforestation, etc. The utilization of land for constructing the power plants, transmission lines, substations and distributing stations is an important ecological issue and also construction of these conventional structures is a tedious process, which disturbs the region's ecology, hydrology and biodiversity. This has necessitated an exploration for sustainable sources of electricity generation which are renewable, clean and cost effective (Environmental Health and Engineering, Inc., 2011, P: 10, TERI Energy Data Directory & Yearbook, TERI Press, New Delhi, 2011). Renewable sources currently contribute only 10% to the nation's power basket where coal is the dominant source (56.81%). India ranks fifth in the world with 15,691.4 MW grid-connected and 367.9 MW off-grid renewable energy based power capacity. Solar energy is the promising renewable source of energy which is widely available in the country. India receives an annual average insolation more than 5 kWh/m^2/day and has over 300 clear sunny days in a year (Polo et al., 2010, P: 2395). India receives good solar radiations and yet utilization of solar energy is limited to 1% due to technological and economic barriers (World Institute of Sustainable Energy, Pune, 2011, P: 57). In this scenario, technologies like solar PV, rooftop solar, solar thermal systems are indeed helpful since these are decentralized, require no waste disposal area and consume very less water (Mitavachan and Srinivasan, 2012, P: 163). India receives abundant solar energy above 5 kWh/m^2/day over 58% of its land area. Efficient solar conversion technologies have the capacity to augment the nation's regional lighting, heating and motive electricity requirements. This can potentially avoid extension of electricity grid to remote places and hence minimise the need for further fossil fuel based centralised capacity addition. Promisingly, solar conversion technologies are being promoted for off-grid electricity generation through congenial policies in India (Ministry of New and Renewable Energy, GoI, 2011, P: 18).

Solar energy has a wide range of applications by converting it into thermal energy and electric energy. Parabolic trough system, central receiver system or parabolic dish system for solar-thermal energy conversion is used (Handbook of solar radiation, Allied Publishers, New Delhi, 1981) and photovoltaic cell (PV cell) is used for solar to electric energy conversion. Solar PV cell converts solar radiation into direct current (DC) electric power using photovoltaic effect (Ordonez et al., 2010, P: 2124). The domestic electricity demand in India can be met by installing solar PV modules in an outdoor area or using rooftop PV modules. Rooftop PV system generates direct current (DC) electrical power using photovoltaic effect. This power can be stored in a battery or used as per the requirement. It uses a part of roof area (depending upon the

PV module size and output) for installing PV modules which acts as an energy source. The generated electricity is stored in batteries, used directly or it fed to the grid using inverter circuit (Ramachandra and Subramanian, 1997a, P: 946). The National Solar Mission (NSM) launched in 2010, targets 200 MW off-grid solar based photovoltaic (PV) capacity by the end of its first phase in 2013. Ministry of New and Renewable Energy (MNRE), Govt. of India (GoI), has already achieved more than 38 MW by 2011 [http://www.mnre.gov.in/schemes/offgrid/solar-pv/]. In this study potential assessment is carried out for Uttara Kannada district considering the seasonal variations in the district. Digitization of rooftop area is done to estimate the roof area required to meet the domestic demand of the household using solar PV modules.

1.1 Need of solar potential assessment in Uttara Kannada

Stratified random sampling of household through the structured questionnaire has been carried out to assess the domestic energy requirement. Domestic monthly electricity consumption in Uttara Kannada district ranges from 50 to 100 kWh (per capita consumption is 15 to 20 kWh). Electrical energy utilization for domestic purpose (lighting, heating, etc.) tops the consumption followed by irrigation. Few small scale and medium scale industries are present in Taluk places (towns) which have the electricity consumption of 150-200 kWh per month (or lesser than 500 kWh/month) (Alam Manzoor, Sathaye Jayant and Barnes Doug, 1998, P: 2). However the district is completely dependent on grid connected electricity supply which is not reliable and does not reach remote localities. Decentralized power supply system can meet the domestic and irrigation demand of the villages and also helpful in electrifying the remote consumers.Solar PV is a promising technology which can generate sufficient electricity to meet the household and irrigation demand (Ramachandra and Krishnadas Gautham, 2011a, P: 85). Large scale deployment of solar based technologies entails solar potential assessment considering seasonal variability of solar radiation.

Abundant solar energy (5.42 kWh/m^2/day) available in the region helps to meet the lighting and heating energy requirements (domestic consumption) through decentralized solutions such as rooftop solar PV systems. It directly converts solar energy into electrical energy using photoelectric effect which can feed the lighting and heating appliances of the household. Study of season wise variations in solar radiation is helpful in allocating the PV modules and forecasting the electricity generation.

2. OBJECTIVE

The main objectives of the study is to i) assess the scope for solar energy considering the seasonal variability of solar radiation in Uttara Kannada, ii) estimation of household electricity demand, iii) extent of roof top available for deploying solar panel to meet the electricity demand of the respective households, iv) extent of land requirement to meet the demand of irrigation pump sets using solar PV and v) techno-economic analysis of rooftop PV system.

3. MATERIAL AND METHODS

3.1 Study Area: Uttara Kannada with the spatial extent of 10,291 km^2 is located at 74°9′-75°10′ E and 13°55′-15°31′ N in the mid-western part of Karnataka state, India (Figure 1). The regions with undulating hills, rising steeply from a narrow coastal strip bordering the Arabian Sea to a plateau at an altitude of 500 m, with occasional hills rising above 600 to 860 m lies in the central part of Western Ghats (Ramachandra and Subramanian, 1997a, P: 947). Figure 2 illustrates the topographic undulations of the region. Topographically, the district lies in three distinct zones namely narrow and flat coastal zone, abruptly rising ridge zone and elevated flatter eastern zone. The coastal zone is thickly populated with coconut clad villages. Ridge zone is a part of the main range of Western Ghats, which runs north to south, parallel to the coast. The flat eastern zone joins the Deccan plateau. The taluks, which comprises the narrow flat coastal zone, are: Karwar, Ankola, Kumta, Honnavar and Bhatkal. Similarly, taluks, which comprises the ridge zone, are: Supa, Haliyal, Yellapur, western Sirsi, and western Siddapur. Flatter eastern zone includes Mundgod, eastern Sirsi and eastern Siddapur. Four agro-climatic zones based on geography and climate are coastal, evergreen, dry deciduous and moist deciduous. There are 1291 villages, 7 towns, 5 city municipal corporations/town municipal corporations/outward growth/census towns and 2 reservoirs in the district [http://uttarakannada.nic.in/].

4. DATA AND METHODS

The study includes assessment of energy at supply side and demand side and is detailed in Figure 3. The supply side includes assessment of regional solar energy availability, spatial extent of rooftop (individual households) and waste land (in the respective villages). The demand side includes estimation of domestic electricity consumption in households and irrigation as well as the extent of rooftop/land area required for installing PV based systems to meet the decentralised demand.

4.1 Assessment of solar energy potential: Village-wise solar energy availability in Uttara Kannada was assessed using satellite-based high resolution global insolation data derived on prudent models. Two datasets collected were:

i. Surface Meteorology and Solar Energy (SSE) 1°x1° (~100 X 100 km) spatial resolution global horizontal insolation (GHI) data provided by National Aeronautics and Space Administration (NASA) based on satellite measurements of 22 years (July 1983 to June 2005) (Surface Meteorology and Solar Energy Release 6.0 Methodology, NASA, 2012);

ii. Higher spatial resolution 0.1° X 0.1° (~ 10 X 10 km) GHI data furnished by the National Renewable Energy Laboratory (NREL) based on satellite measurements of 7 years (January 2002 to December 2008) (NREL GHI data furnished by National Renewable energy Laboratory, 2010). These were compared and validated with long term surface GHI measurements based interpolation model for the region.Higher resolution NREL GHI data were used to study the seasonal availability and variability of village-wise solar energy in Uttara Kannada. Seasonal solar maps were generated using Geographic Information Systems (GIS) tools (Ramachandra, Krishnadas Gautham and Jain Rishab, 2012a, P: 8).

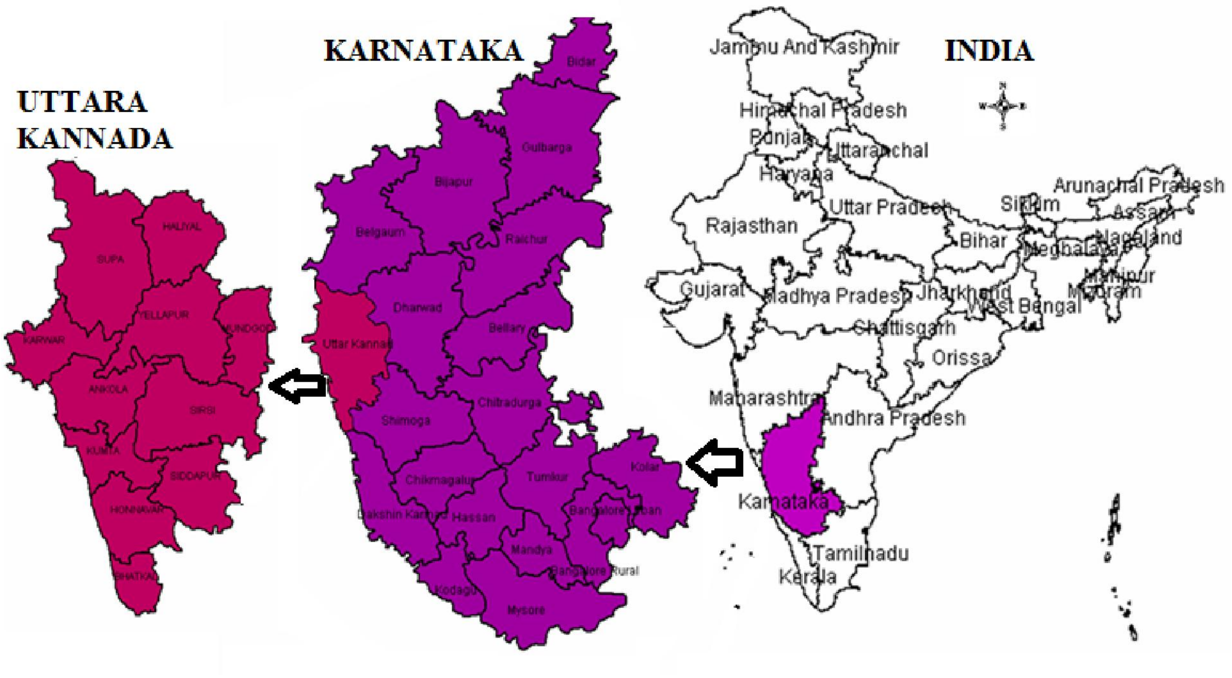


Figure 1: Location of Uttara Kannada

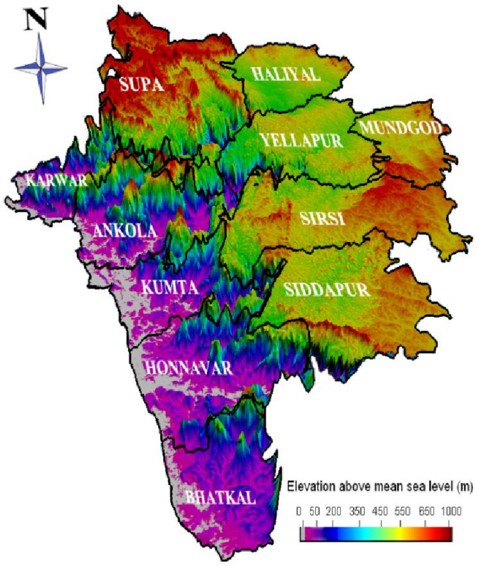
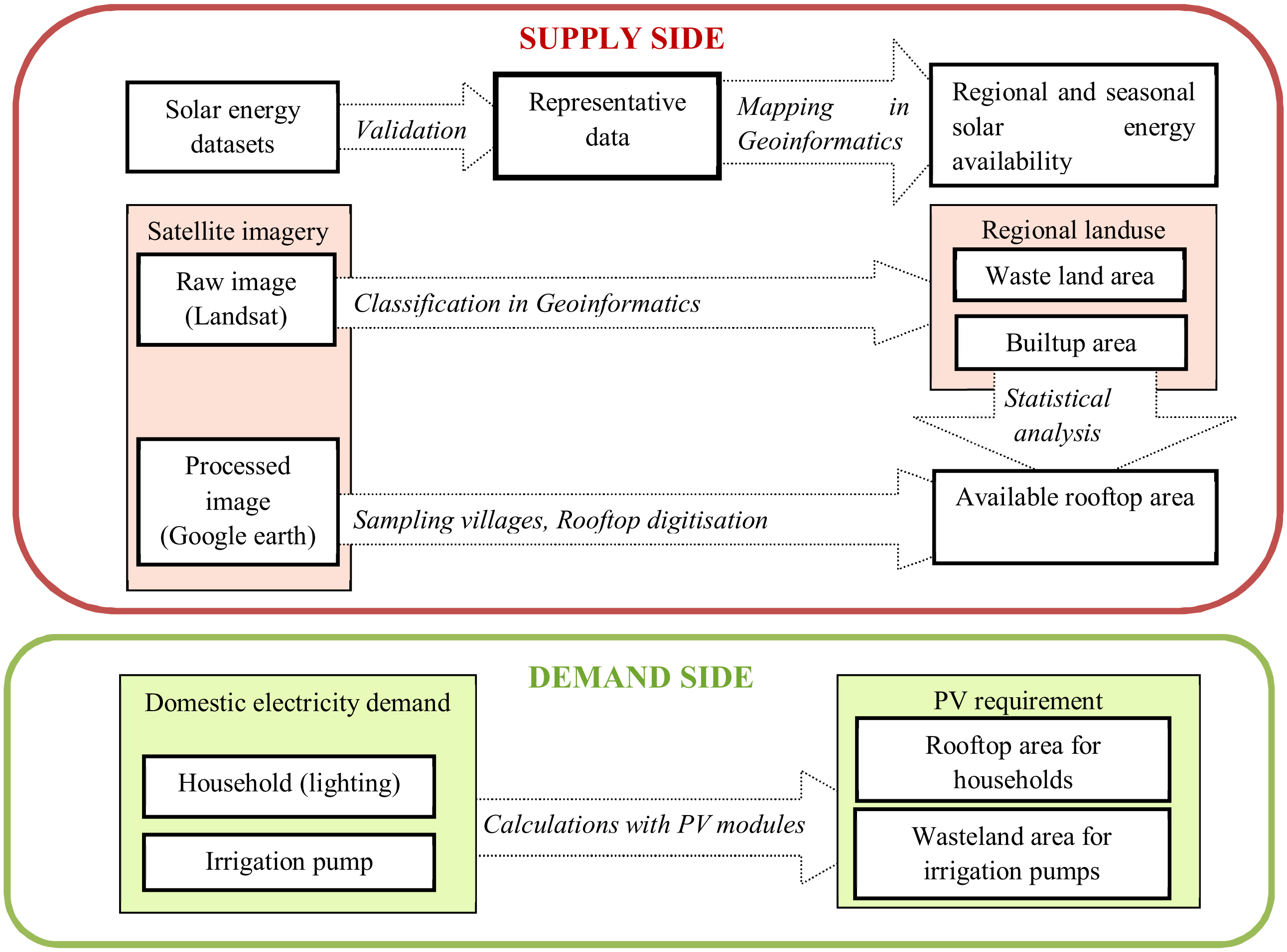


Figure 2: Digital Elevation Model of Uttara Kannada, Karnataka



4.2 Estimation of Builtup and Rooftop area (Digitization of rooftop area)

4.2.1 Estimation of Built-up area: Multispectral data acquired through IRS (Indian Remote Sensing) P6 satellite of 5.8 m resolution was used to estimate the extent of human habitations. Remote sensing data were analysed through standard protocols involving geometric correction, image classification through Gaussian maximum likelihood classifier. The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data (IRS P6) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India (1:50000, 1:250000). Analysis of remote sensing data (Ramachandra, Aithal and Durgappa, 2012, P328-333) involved i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land use analysis was carried out through open source program GRASS - Geographic Resource Analysis Support System (http://grass.fbk.eu/) using supervised pattern classifier - Gaussian maximum likelihood algorithm using probability and cost functions (Ramachandra, Aithal and Durgappa, 2012, P328-333). Accuracy assessment to evaluate the performance of classifiers, was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients and proportion of correctly allocated cases. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies. Application of maximum likelihood classification method resulted in accuracy of 88%. Remote sensing data analysis provided i) area under vegetation (forests, grass lands.), ii) built up (buildings, roads or any paved surface, iii) water bodies (lakes/tanks, rivers, reservoirs), iv) others (open area such as play grounds, quarry regions, etc.).

4.2.2 Estimation of the spatial extent of rooftops: Regional rooftop area availability for harvesting solar energy was calculated using remote sensing data through geo-informatics and statistical tools. Villages representing different agro-climatic zones of Uttara Kannada were randomly chosen and rooftop areas were mapped by manual digitisation of high resolution Google Earth satellite data (http://googleearth.com) with the support of geo-informatics tools (Ordonez et al., 2010, P: 2124, Ramachandra, 2007, P: 108). Roof types in towns and other urban areas were similar in most of the zones, one random sample was manually digitised for estimating the spatial extent of rooftops. The built-up areas for randomly sampled regions and manually digitized total rooftop areas were investigated using statistical tools. Total rooftop areas were extrapolated for other regions based on two different methods:

i) **Method 1– Census based:** Ratio of total rooftop area to number of households (census) in sampled regions provided average rooftop area per household $(R/H)i$ for respective agro-climatic zones i. These ratios were used to derive total rooftop areas Ri in other regions based on number of households Hi from the census, as shown in equation 1. R/H value for towns were taken as same in all agro-climatic zones.

$$Ri = Hi * (R/H)i \qquad (1)$$

where,
Ri is the total rooftop area of households in ith agro-climatic zone in m^2
Hi is the number of households in ith agro-climatic zone

ii) **Method 2–based on Land Use Land Cover (LULC):** Signature separation corresponding to LU (Land Use) classes is done using Transformed Divergence (TD) matrix and Bhattacharya distance. Accuracy assessment is done using error matrix in order to get most precise results (Ramachandra, Joshi and Kumar Uttam, 2012, P: 3). Ratios of total rooftop areas to built-up areas in sampled regions were averaged $(R/B)i$ over different agroclimatic zones i. Ratios with large deviations were removed due to possibility of misclassification. The average ratio values for respective zones were used to derive total rooftop areas Ri in other villages, as shown in equation 2.

$$Ri = Bi * (R/B)i \qquad (2)$$

where,
Bi is the total-built up area in i^{th} agro-climatic zone

4.3 Regional domestic electricity demand: Taluk wise electricity consumption data were collected from the respective government agencies. Apart from this, stratified random sampling of 1,700 households representing all agro-climatic zones yielded energy requirement per household. Based on this data, monthly electricity usage (in kWh) for household for purposes like lighting, heating etc, and irrigation pump sets were computed (Ramachandra, Joshi, et al., 2000, P: 825).

4.4 PV requirement to meet regional electricity demand: Electricity generation from PV was calculated based on the equation 3. The theoretical energy output from a PV cell,

$$Eth = G * A * \eta = G * \frac{P}{Istc} \qquad (3)$$

where G is the Global Horizontal Insolation (kWh/m^2), A is the area of the PV panel, P is the rated power output, $Istc$ is the insolation at standard test conditions and η is the efficiency.

Actual energy output considering the quality factor,

$$Eload = Eth * Q \qquad (4)$$

where Q is the quality factor of a PV module. Hence wattage of PV to be installed is found by

$$P = Eload * \frac{Istc}{G*Q} \qquad (5)$$

Area required to meet the demand is,

$$A = \frac{Eload}{G*\eta*Q} \qquad (6)$$

The built-up areas for randomly sampled villages and manually digitized roof-top areas were compared using parametric tests (paired t-test) (Sampling Techniques, C.E.C.S.A., 1975). Ratio of total rooftop area to number of households (census) in sampled villages provided rooftop area per household for respective agro climatic zones. These ratios were used to derive rooftop areas in other villages based on number of households. Percentage share of manually digitized rooftop area in the total classified built-up area for sampled town was estimated. This factor was used for all other town panchayats and municipalities to estimate rooftop areas available. Computed rooftop area is assumed to be available for installing solar energy applications like photovoltaic panels, water heaters, etc. to meet the lighting and water heating requirement of respective houses.

Figure 4 depicts the digitized rooftops in Lakolli village of Mundgod Taluk in Uttara Kannada. The polygons of exposed (available) rooftops in a village are manually digitised using Google Earth. Rooftops in 30 random regions (including one town) spread across four agro-climatic zones of Uttara Kannada were similarly digitised. Rooftop area per household $(R/H)i$ was calculated for the sampled villages and averaged over each agro-climatic zone respectively. These are given in Table 1 and details of villages/towns in Appendix I.

5 RESULTS AND DISCUSSION

5.1 **Solar energy potential (Seasonal variations of solar insolation) assessment in Uttara Kannada:** The monthly average GHI (Global Horizontal Irradiance) datasets from NASA and NREL were compared and validated with surface data based model. Figure 5 illustrates the monthly variability of solar radiation. The values indicate that adequate solar energy is available in the region. Higher resolution NREL GHI data were used to study the solar energy potential in Uttara Kannada. Solar maps generated for monsoon, winter and summer seasons, show seasonal availability and regional variability of GHI (Figure 6). The seasonal average GHI is highest in summer (6.65 – 6.95 kWh/m^2/day), moderate in winter (5.70 – 5.85 kWh/m^2/day) and lowest in monsoon (4.50 – 5.20 kWh/m^2/day). Annual average GHI values were considered for assessing the technical potential of solar energy in Uttara Kannada.

Figure 6 illustrates the seasonal variations of solar insolation in Uttara Kannada. Solar insolation ranges from 4.5 to 6.95 kWh/m^2/day in the districts throughout the year. During Monsoon season, district gets the insolation ranges from 4.5 to 5.2 kWh/m^2/day. Coastal and the eastern part of the central (moist deciduous) region receives insolation of 4.8-5 kWh/m^2/day. The central region (Evergreen) gets the lowest insolation ranges from 4.5 to 4.8 kWh/m^2/day during monsoon. Eastern most part (dry deciduous) receives higher insolation of 4.89-5.2 kWh/m^2/day.

In winter, insolation in the district ranges from 5.70 to 5.85 kWh/m^2/day. Most of the parts in the district receive insolation of 5.80-5.85 kWh/m^2/day. Eastern region of the district (dry deciduous) gets insolation ranges from 5.75 to 5.80 kWh/m^2/day. Some parts in this region receive insolation of 5.70-5.75 kWh/m^2/day also.

Figure 4: Rooftop digitisation in Lakolli village of Mundgod taluk, Uttara Kannada

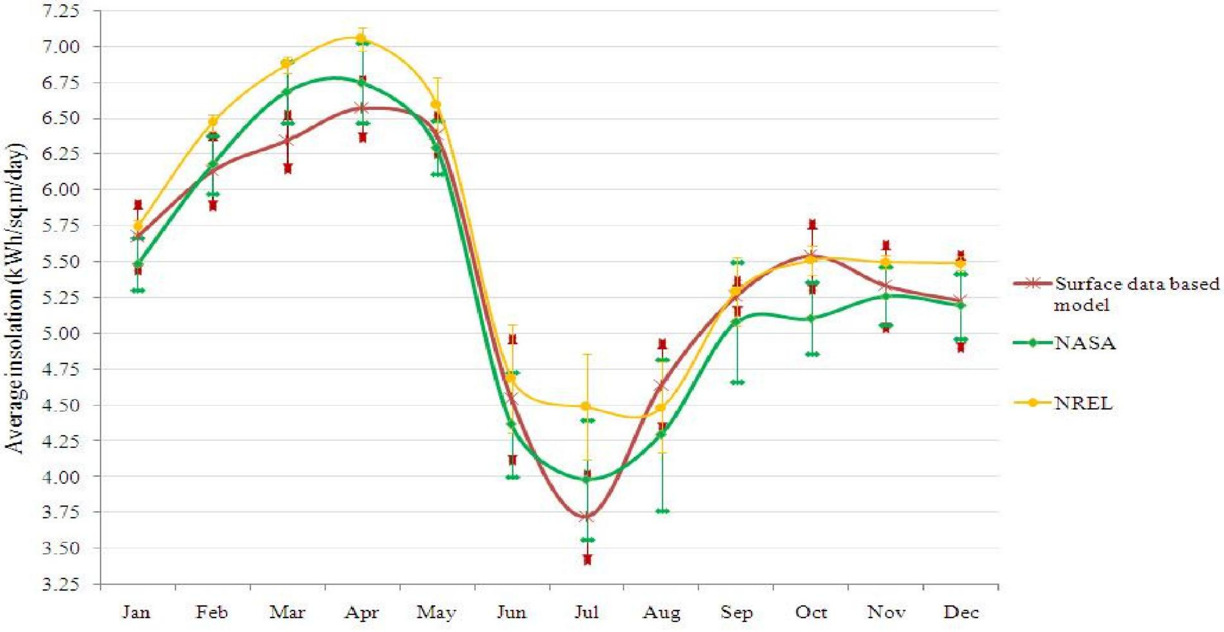


Figure 5: Comparison of different available solar data for Uttara Kannada

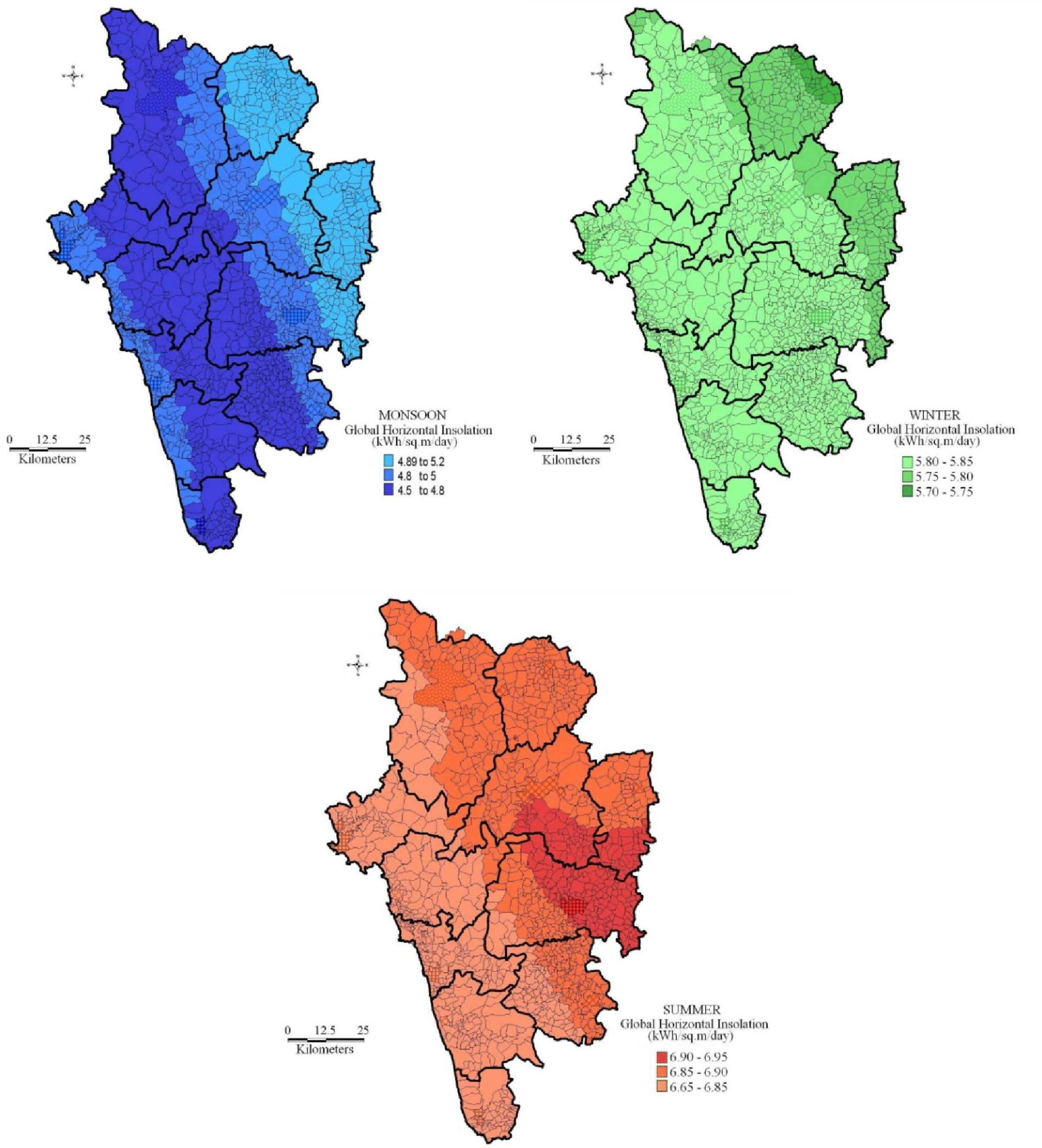


Figure 6: Seasonal variations of solar radiation in Uttara Kannada

Uttara Kannada gets higher insolation ranges from 6.65 to 6.95 kWh/m^2/day in summer. Western part of the district receives insolation of 6.65-6.85 kWh/m^2/day. Most of the eastern part (central) gets insolation of 6.85-6.90 KWh/m^2/day. In summer, some parts of the district get higher insolation of 6.90-6.95 kWh/m^2/day.

Uttara Kannada has a good solar potential and can meet the energy demand in the domestic sector. Energy harvesting through PV based solar system mounted on rooftops of individual houses would help in meeting the respective house's energy demand while bringing down the dependency on the State's grid.

5.2 **Land use Dynamics in Uttara Kannada:** Figure 7 shows the land use details of a sampled village in Uttara Kannada. Classification of all sampled villages provided built-up and waste land areas. Based on the rooftop areas already calculated, rooftop to built-up ratio $(R/B)i$ was derived for sampled villages and averaged over each agro-climatic zones respectively (Table 1).

Table 1: Average values of R/H and R/B ratios for different agro-climatic zones

Agro-climatic zone	R/H	R/B
Coastal	72	0.4
Dry deciduous	141	0.5
Evergreen	139	1.6
Moist deciduous	82	0.5

Based on methods 1 and 2 (data and methods section, equations 1 and 2), the averaged *R/H* and *R/B* values were used to derive total rooftop areas in all regions and represented in Figures 8 and 9 respectively. It is observed that Method 1 provides a lower estimate of region-wise rooftop area compared to Method 2.

From Figure 8 (Method 1: Extrapolation) it is seen that in most of the villages, total roof area available is less than 10,000 m^2 or it is about 10,000 to 25,000 m^2. There are very few villages where the total roof area is more than 50,000 m^2. By the knowledge of total number of households in the particular village available rooftop area of each house can be determined.

Figure 9 (Method 2: land use) gives the total roof top area available in the villages of Uttara Kannada. It shows that total rooftop area available is more than 1,00,000 m^2 in most of the villages. There is significant number of villages where the total roof area of the village is less than 10,000 m^2. In some of the villages total roof area available ranges between 50,000 to 1,00,000 m^2. Method 2 is based on the signature values of the land use (LU) over estimate the total roof area due to the approximation and lower pixel resolution. However both the results are comparable in the present case and the error is less.

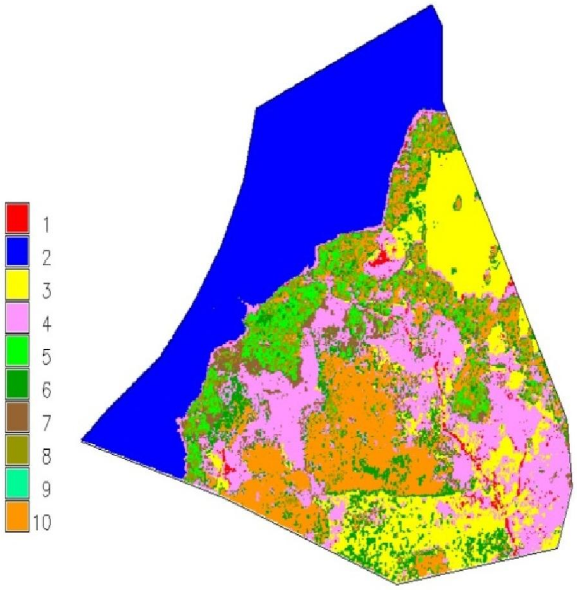


Figure 7: Land use in Aghanashini village of Kumta taluk, Uttara Kannada

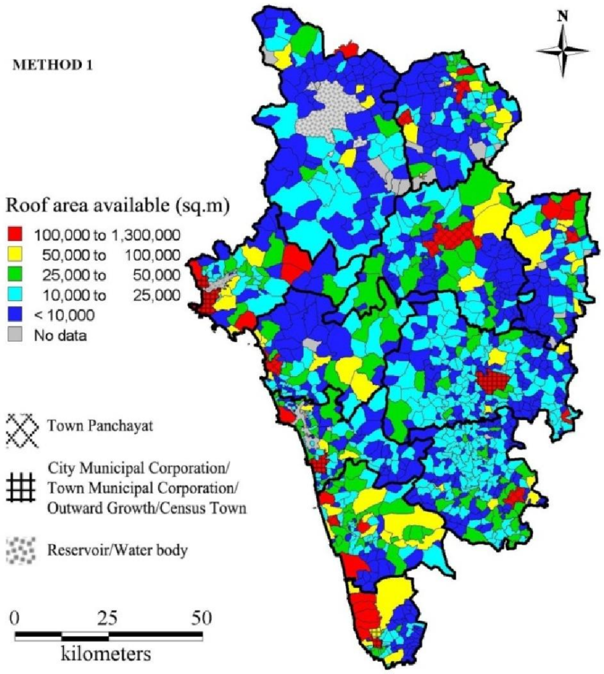


Figure 8: Region wise rooftop area available based on Method 1

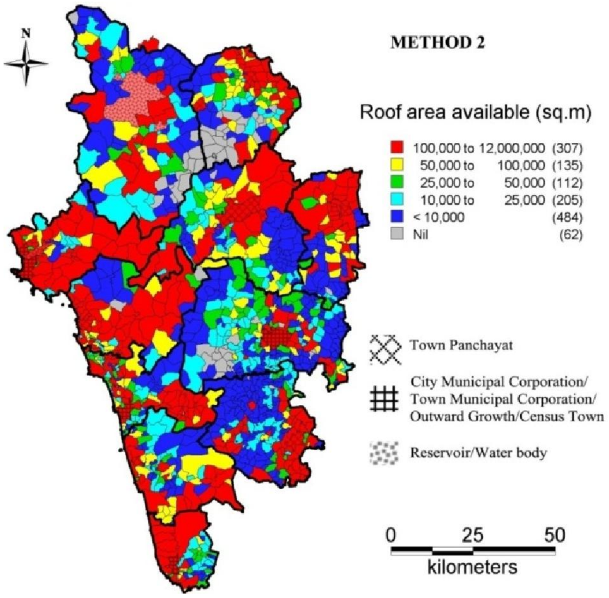


Figure 9: Region wise rooftop area available based on Method 2

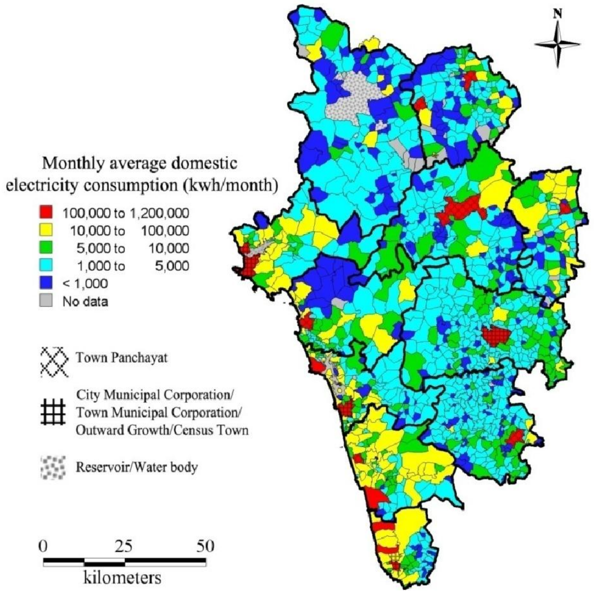


Figure 10: Domestic household electricity consumption

5.3 Domestic electricity consumption: Table 2 summarises taluk-wise monthly average domestic electricity consumption based on the data compiled from the government agencies and from sampled households. Average monthly energy consumption of electricity for domestic purposes is about 34±8 kWh per month per household and irrigation requirement is about 3218±2412 kWh/hectare/year. Monthly domestic electricity consumption ranges from

23 (for Haliyal) to 44 (Honnavar) kWh. These values were used for calculating the region wise electricity demand for domestic and irrigation. Coastal taluks (Ankola, Kumta, Karwar, Bhatkal and Honnavar) have higher household electricity consumption. Siddapur and Sirsi taluks with vast extent of horticulture crops lead in the per hectare consumption of electricity for irrigation. Figure 10 gives the monthly average household electricity consumption and Figure 11 shows the annual average electricity consumption for pump irrigation. A large part of Uttara Kannada except the coast is rainfed and hence do not rely on irrigation for agriculture. The electricity consumption ranges from 1,000 - 5,000 kWh/month. There are about 80 villages, which have the domestic consumption of 10,000 to 1,00,000 KWh of electricity in a month.

Table 2: Domestic electricity consumption

Taluk	Household consumption (kWh/month)	Agricultural consumption (kWh/ha/year)
Ankola	34	2900
Kumta	42	3200
Karwar	40	3100
Bhatkal	40	3100
Honnavar	44	1800
Haliyal	23	1800
Mundgod	37	2100
Siddapur	26	7700
Sirsi	34	7900
Yellapur	25	900
Supa	25	900
max	44	7900
min	23	900
average	34	3218
std.	8	2412

5.4 Scope for rooftop PV systems to meet domestic electricity demand: The monthly average electric energy consumption per household is about 50 to 100 kWh in Uttara Kannada. This electricity demand can be met through solar rooftop PV system, which ensures continuous supply of electricity compared to the current system of depending on grid with uncertainties. The rooftop area required to generate the electric energy using PV which will meet the domestic electricity demand in respective villages is given in Figure 12. Majority of the villages require rooftop area less than 250 m^2 to meet the electric energy demand using solar PV system. Around 26% (350) of the villages in the district require rooftop area less than 100 m^2 and about 27% (363) places need rooftop area ranges from 100 to 250 m^2. Hence more than 54% of the villages require rooftop area less than 250 m^2 to meet the current domestic electricity demand. In very few places total rooftop area required is

10,000 to 1,00,000 m^2 which are normally the city or town municipal corporations or census towns.

Rooftop area requirement for PV modules was computed and mapped (Figure 12) with the knowledge of region-wise household electricity demand considering the solar PV panels of efficiency (η) 14% with modules of quality factor (Q) 0.5 as discussed in Methods section. In most of the regions, except for towns, less than 10,000 m^2 of rooftop area was sufficient to meet the village's household electricity demand. Figure 13 shows the PV capacity required to meet their demand. Most of the villages required installations within 1,000 kW while towns demanded larger installations upto 14,000 kW per region. Figures 14 and 15 provide information on the share of available rooftop area required to meet household electricity demand, based on methods 1 and 2 respectively.

Figure 14 (Method 1: Extrapolation) gives the share of (% of) available roof area required to meet the domestic electricity demand of household using rooftop PV system. In almost all the villages in the central part (Evergreen region) of the districts, only 1-2% of the available roof area is required to meet the electric energy demand of the household using rooftop PV system. In few villages in coastal region (HonnavarTaluk), 5-7% of the available rooftop area is needed to meet the present household electricity demand. In all other villages, roof area required is less than 5% (or 2-5%) of the total area to meet the demand using solar rooftop PV system. Hence study reveals that, a small part (less than 7%) of the roof area is sufficient to meet the electrical energy demand of the household using rooftop PV system in the district.

As mentioned before, availability of rooftop area according to method 1 was a lower estimation. Based on this method, less than 7% of the available rooftop area in any region can meet its household electricity requirement using PV. As expected, due to the higher estimation of available rooftop area by method 2, less than 5% can meet this demand using PV in most of the regions. In certain regions where the built-up areas were not classified (due to dense tree canopy, covering the rooftops) and hence rooftop areas were not available according to method 2, it is shown as “roof not sufficient” to meet the demand (Figure 15).

Figure 15 (Method 2: LULC-Land Use and Land Cover) gives the percentage of roof area required to meet the domestic electricity demand using PV. It also shows that in most of the villages, the roof area required to meet the electricity demand of the household using rooftop PV is less than 1%. In some places area required ranges from 1-5 and in few places it is 50-100%. But overall the roof area required is less than 5% to meet the domestic demand of the household using rooftop PV system.

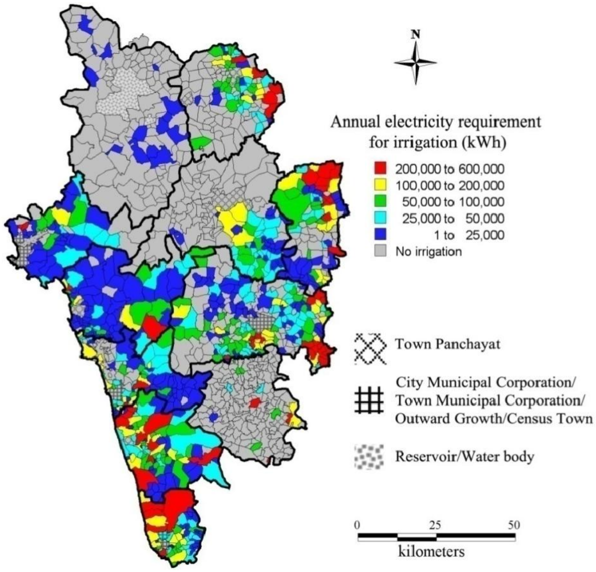


Figure 11: Electricity requirement for pump irrigation

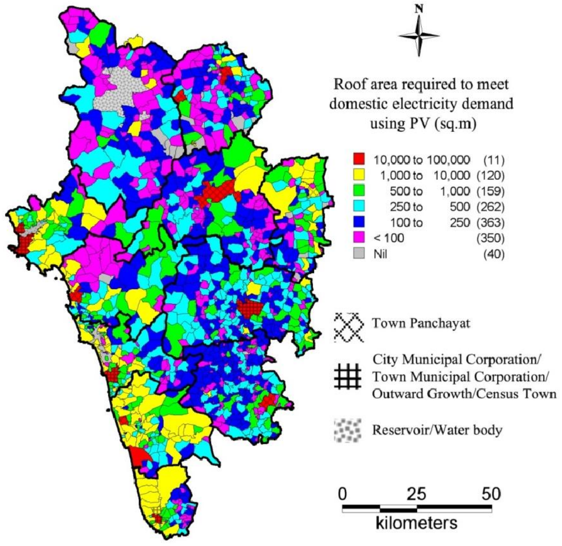


Figure 12: Region-wise rooftop area required to meet household electricity demand using PV (η=14%, Quality factor=0.5)

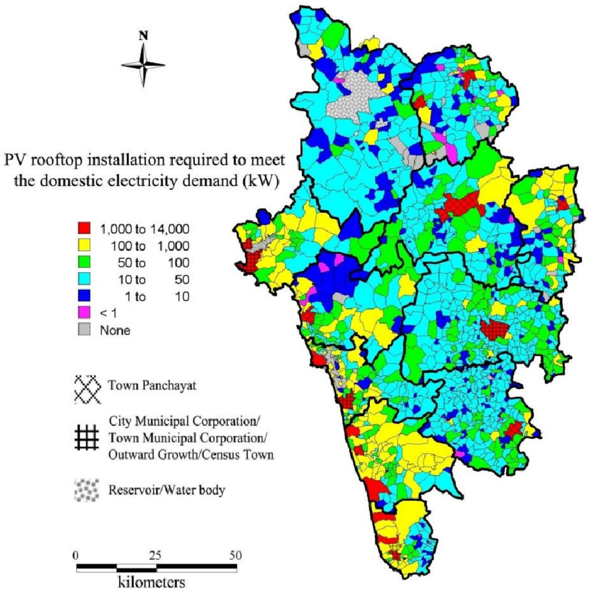


Figure 13: Region-wise PV rooftop installation required to meet the household electricity demand

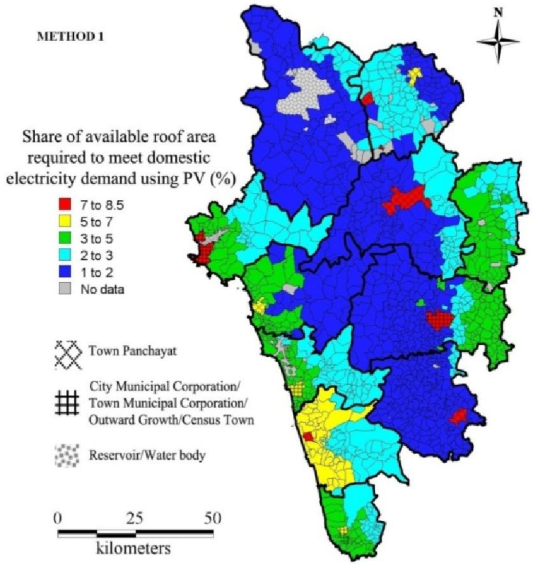


Figure 14: Share of rooftop area required to meet household electricity demand

5.5 Meeting the electricity demand of irrigation using Solar PV in waste/open land

Village-wise land uses were estimated using IRS (Indian remote Sensing) P6 data of 5.6 m spatial resolution. This analysis provided the details of the extent of wasteland in each village of the district. The proportion of wasteland required to meet electricity demand for irrigation was calculated as discussed earlier (Method section). Figure 16 shows the waste land required to meet the annual electrical energy demand for irrigation considering SPV Standalone panels of efficiency (η) 14% and quality factor (Q) 0.5. Most part of the district is practices rain-fed cultivation without much irrigation. Villages in the coastal zone can meet the irrigation demand with less than 0.5% of the available waste land area. In most of the villages' total electrical energy required for irrigation ranges from 1 to 25,000 kWh per annum. In some places energy requirement is more than 25,000 kWh and less than 50,000 kWh annually. There are few places where the total electrical energy required for irrigation is more than 1,00,000 kWh per annum. The land requirement analysis shows that the electricity demand for irrigation purpose can be met using less than 0.5% of wasteland area in the district. In few places waste/open land area required is more than 0.5% of the totalwaste/open land area available. However, in Uttara Kannada waste/open land area required will be less than 10% to meet the electricity demand of irrigation by installing PV modules.

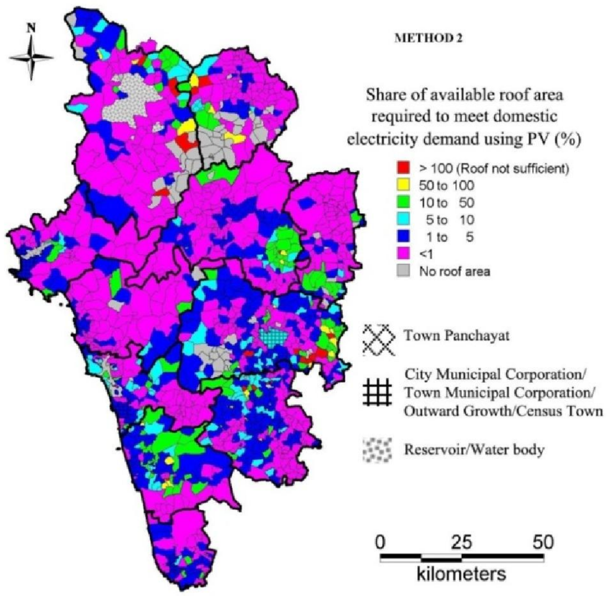


Figure 15: Share of rooftop area required to meet household electricity demand based on method 2

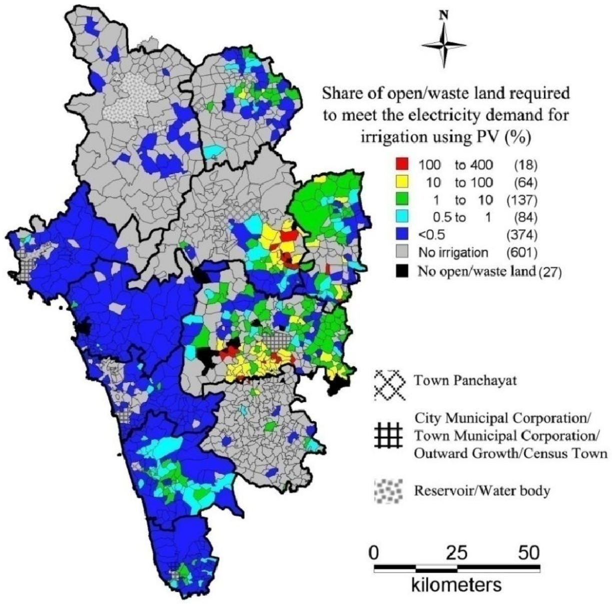


Figure 16: Share of waste land area required to meet electricity demand for irrigation using PV

6 TECHNO-ECONOMIC ANALYSIS OF ROOFTOP PV SYSTEM

Electrical energy at household levels is mainly used for end uses such as lighting, heating and pumping of water. The household electricity demand is currently being met by the grid connected system which has its own limitations (Raghavan Shubha. V, et. al., 2011, P: 3180). Many households in the state depend on battery-inverter or diesel generator as a backup system which increases the household expenditure. Also, over 400 million people do not have access to electricity (13 villages in Karnataka) in the country. Hence the decentralized rooftop solar PV systems at individual household level could be the technically feasible solution as it can meet the demand of the household and meeting the increasing demands of rural (remote area) electrification (Ramachandra, Krishnadas Gautham and Jain Rishab, 2012a, P: 3179).

Monthly average electricity consumption of a household in Karnataka (Uttara Kannada district) ranges from 50 kWh to 100 kWh. The average roof area of an urban household is about 1,200 square feet (120 m^2) and that of rural household is 2,000 to 2,500 square feet (200-250 m^2). The portion of this rooftop is sufficient to harvest electrical energy using solar photovoltaic (SPV) system. Table 3 gives the area of PV cell required to generate electric energy at varied efficiencies (like 4, 8, 12 and 16%). Rooftop SPV is a standalone or an off grid system and hence do not face any uncertainty such as grid interventions and hence it would be more reliable. The system uses a part of rooftop area for installing PV modules which will be less than 5% of the total roof area. Though the initial cost of such systems is high, it has a payback period of 5 to 7 years and has a life span of more than 20 years (Jain Abhishek, 2012, <http://www.bijlibachao.in/Solar/roof-top-solar-pv-system-project-for-home-and-office.html>).

Table 3: Rooftop area (m^2) required for installing SPV[1]

PV module efficiency (%)	**PV capacity (Watts)**	**100**	**250**	**500**	**1000**	**2000**	**4000**	**10000**
4	Rooftop area required (m^2) for SPV	30	75	150	300	600	1200	2400
8		15	38	75	150	300	600	1500
12		10	25	50	100	200	400	1000
16		8	20	40	80	160	320	800

[1] Ministry of New and Renewable Energy (GoI)

For example, to generate 1,000 watts of electricity from 12% of efficiency, 100 m^2 roof area is required. But this does not give the output for 24 hours a day and all throughout the year. The electricity generated (kWh) from the PV system depends on the panel efficiency and the availability of solar insolation in a location. The factor that defines this output is called CUF (Capacity Utility Factor). For India, it is typically taken as 19% and the energy generated is:

$$\text{Energy Generated Annually (in kWh)} = \text{System Size in KW} * \text{CUF} * 365 * 24 \tag{7}$$

A typical 1 kW capacity solar system will generate 1,600-1,700 kWh of electricity per year. (It may vary according to the location and PV technology used.) This means electrical energy generated per month from rooftop PV system ranges from 130 to 140 kWh (consumption in household is 50-100 kWh). Roof area required for 1KW output PV system ranges from 300 m^2

(η=4%) to 80 m^2 (η=16%) (Installing and Maintaining a Home Solar Electric System, 2012, <http://energy.gov/energysaver/articles/installing-and-maintaining-home-solar-electric-system>).

Roof area required to meet the monthly demand of a household is estimated for different PV technologies is given in Table 4 considering the average solar insolation of 5 kWh/m^2/day. Area calculated is the actual area of PV module to be installed to meet the demand on rooftop.

Table 4: Fraction of rooftop area required for various PV cell technologies

Household with available rooftop area of 100 m^2					
Monthly demand	Type of PV module and η				
	Crystalline-Si η=15-20%	Amorphous-Si η=5-7%	Cadmium-Telluride, η=8-11%	CIGS/CIS η=8-11%	
30	1.33	4.00	2.50	2.50	% rooftop required
50	2.22	6.67	4.17	4.17	
100	4.44	13.33	8.33	8.33	
200	8.89	26.67	16.67	16.67	

6.1 **Economic Analysis:** Table 5 gives the total installation cost of a typical rooftop PV system with the generation cost and payback period. Solar PV module of 1 kW$_p$ with overall system efficiency of 10% is considered for the calculations (Lacchini Corrado, João Carlos and Santos Dos, 2011, P: 183). The costs estimated include all the system components such as battery, wiring and mounting equipment (does not include inverter and backup unit).

Table 5: Unit cost and payback period for SPV system[1,2]

PV module type	Capacity	Cost (Rs/W$_p$)	Total installation cost	Unit cost Rs/KWh	Payback period
Crystalline-Silicon PV modules with conversion efficiency of 14-20%	**1 KW$_p$** Amount of roof space required for the installation of 1 KW$_p$ PV module ranges from 8-12 m^2	**180** The cost of installed plant capacity of rooftop SPV is about 18 crores/MW	**1,80,000** Total cost of 1 KW$_p$ system	**15-19** (Without any discount)	**Generally 5-7 years.** (Less than 10 years)

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[1] Alan Goodrich, Ted James and Michael Woodhouse, 2011. Residential, Commercial, and Utility-Scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-Reduction Opportunities. Technical report by NREL, NREL/TP-6A20-53347, February 2012

[2] Alice Solar City 2011. Rooftop solar photovoltaic (PV) system, part of the Australian Government's Solar Cities Initiative

Photovoltaic cells directly convert solar radiations into electric power due to the process called photo electric effect. When sun light falls on the surface of PV cell, free electrons are emitted from the cell which flows through the external circuit and delivers the power. The output power is unidirectional or DC power. Normally rated output power is measured in peak Watt (W_p) in standard test condition (STC) which is the product of short circuit current (I_{sc}) and open circuit voltage (V_{sc}). The actual output of the panel may vary according to the location and insolation over the year (seasonal variation). The mean DC output power in Indian climatic conditions ranges from 1,600 to 1,700 kWh per year per kW_p (Vardimon Ran, 2011, P: 592).

The other important aspect which affects the output of the panes is the efficiency which is calculated by measuring the net output of the PV of unit square metre area. The efficiency varies for different materials depending on purity of the silicon and manufacturing technology. For crystalline Silicon, efficiency ranges from 12 to 16% and maximum efficiency achieved is more than 40%. Amorphous silicon, Cadmium Telluride (CdTe) and CIGS (Copper indium gallium selenide) solar cells have lower efficiency of 5-7%, 8-11% and 8-11% respectively (International Finance Corporation (IFC), A Member of World Bank Group, 2011). Cost of the rooftop PV solar system varies from 1.5 to 1.8 lakhs per KW_p installed capacity. Cost may also depend on the other parameters like efficiency, capacity, type of PV cell technology, type of mounting and the geography. Table 6 gives the cost comparison of different power plant on installed capacity basis.

Table 6: Installed plant capacity cost comparison[1,2,3] (Cost/MW)

Type of Power Plant	Cost (Rs/MW) in crores
Coal based (Thermal power plant)	4.5
Hydroelectric	5.5
Nuclear	13
Wind	4 – 5
Solar PV (Grid connected)	20
Solar PV (Rooftop)	1.5 – 1.8 lakhs/KW_p

1. Nuclear Fissionary, < http://nuclearfissionary.com/2010/04/02/comparing-energy-costs-of-nuclear-coal-gas-wind-and-solar/>
2. http://aglasem.com/resources/reports/pdf/SOLAR%20VS%20NUCLEAR%20VS%20WIND%20ENERGY.pdf,
3. http://openaccesslibrary.org/images/HAR224_Adesh_Sharma.pdf,

The installation cost of solar PV and rooftop PV are comparable to other technologies and has a payback period of 5 to 7 years. Moreover solar PV system has very less maintenance cost and minimal issues of waste disposal. Also, rooftop solar PV uses the roof space with no landuse restrictions (Lacchini Corrado, João Carlos and Santos Dos, 2011, P: 185).

Thermal power plants are the base load plants (coal or gas based) which supply the larger loads of the country. These plants are centralized plants normally located close to raw material (coal) available places or near to load centres. Such plants may not be installed as decentralized plants for a community or household level. Nuclear and hydroelectric plants are also centralized plants, installed capacity ranges from few hundreds of MW to several thousands. Due to the waste disposal and recitation constraints nuclear power plants are located far away from load centres and cannot be installed in decentralized manner for community level. Hydroelectric plants are the biggest plants which need large area for dam construction to provide suitable head. But small hydroelectric plants (less than 50 MW) can be constructed to supply a small load centres (community level). Compared to these, solar PV and wind turbine (or hybrid) generation plants can be used as both centralized as well as decentralized to supply community and household level demand. An off grid system may be lower capacity (few hundreds of watts to few KW) which is capable to meet the demand of household or a community demand. Rooftop solar PV systems are the latest development which can meet the household demand and also can supply to the grid. Building-integrated photovoltaic (BIPV) is the upcoming technology in which PV panels are integrated with building materials. (Ramachandra and Dabrase Pramod. S, 2000, P: 15).

6.2 Comparative analysis of Generation cost (Cost per MWh) of different power plants:

Generation cost includes the cost of installation of plant (capital cost), operation and maintenance cost (O&M), cost of the raw materials and other expenses. This cost also includes the life time valuation of a plant to the present value. Table 7 gives the generating cost comparison of different power plants (2010) based on the average of 14 countries including three non OECD countries (International Energy Agency (IEA) Nuclear Energy Agency (NEA), Organization for Economic Co-operation and Development, 2010).

Table 7: Generation cost comparison of different power plants

Type of Power Plant	Rs/MWh (at 5% Discount rate)	Rs/MWh (at 10% Discount rate)
Nuclear	2440.8	4217.24
Coal	3400.2	4643.17
Gas	3877.65	4339.85
Hydro – Small hydro	4743	8501.27
Large hydro	4557.15	8841.65
Wind – Onshore	4887	8346.17
Offshore	6276.15	8999.03
Geothermal	4438.35	7244.28
Solar – PV	12600.45	19058.99
PV (rooftop)[1]	15854	23273.48
Solar thermal[2]	9503.1	14809.73

[1] Solar PV (rooftop) system in Germany,

[2] Solar thermal system in United States

7 ENVIRONMENTAL ASPECTS

On an average, generation of 1,000 KWh of electricity from solar radiations reduces emissions by about 83.6 kg of sulfur dioxide, 2.25 kg of nitrogen oxides and about 635 kg of carbon dioxide. During its 20 years of clean energy production solar rooftop system can reduce tons of poisonous gas emissions to the climate (The National Renewable Energy Laboratory PV FAQs for: U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, 2004).

8 CONCLUSION

Solar energy is the most reliable and widely available renewable energy resource for decentralized applications through thermal and electricity conversion. Domestic applications such as thermal conversion, photovoltaic conversion, solar lighting, cooking etc. are influenced by the reception of solar radiation. Solar insolation varies with geography and season, requiring assessment at local levels. Geographic information system (GIS) based insolation data is used for assessing the potential and design of the system where the variations are in acceptable limit and comparison with ground measurements have given better accuracy. Energy potential is computed based on the digitized roof area data from select villages representing all agro-climatic zones in the region with insolation details. With the knowledge of insolation reception and rooftop digitization considering high spatial resolution remote sensing data (Google earth), available potential is extrapolated to the required region of study. Solar PV installation on roof top could be effective in generating electricity from solar sources to meet the domestic energy demand.

Uttara Kannada district has more than 2,70,000 households, which has the electricity consumption of 50 to 100 kWh per month (per household). In meeting this household domestic demand rooftop solar PV systems could play an important role since district has very good solar potential. The fraction of open/wastelands in the district can be utilized to meet the electricity demand of irrigation pump sets using solar PV system. Since the whole country (in turn states and districts) is becoming an energy deficit place, need of further installation of conventional power plants can be scaled down by using decentralized or standalone unconventional methods such as rooftop PV system. Government is also encouraging the solar energy utilization by projects such as JNNSM: Jawaharlal Nehru National Solar Mission, planned to have 20,000 MW of solar energy based power plants in India. Rooftop PV system can contribute significantly to JNNSM and adequately cutting down harmful greenhouse gases and hence reduction in carbon footprint.

9 RECOMMENDATIONS FOR SUSTAINABLE ENERGY DURING 21ST CENTURY

Solar energy based generation seems promising and environmental friendly option to meet the growing demands. India is blessed with the good solar potential and harvesting this potential would minimize the environmental implications associated with the fossil fuels. Solar PV technology has the potential to meet the domestic and irrigation demands in the decentralized way. Appropriate policy incentives might help in the large scale deployment of solar devices at household levels. There is a need to focus on energy efficient decentralized electricity generation technologies with micro grid and smart grid architecture, which would go long way in meeting the energy demand. In this regard, suggestions are:

1. Electricity generation using SPV and CSP technologies would bridge the demand supply gap as India receives abundant solar energy of more than 5 kWh/m^2/day for about 300 days in a year. The adequate potential with mature technologies and apt policy incentives would help in meeting the electricity demand in a region. Few houses in Uttara Kannada has been using Solar PV for the last 4-5 years (Muroor Kalabe village, etc.)

2. Roof top based SPV would help in meeting the household energy demand in rural as well as urban households. Rural household require about 70-100 kWh per month and to meet this requirement 5-6 m^2 rooftop is adequate (at η=10%, and insolation of 5 kWh/m^2/day) and the average rooftop in rural locations in Karnataka is about 110 m^2 and about 115 m^2 in urban localities.
3. Adequate barren /waste land is available in Karnataka as the available waste land is about 7% of the total geographical area less than 1% area is sufficient to generate electricity required for irrigation and domestic sector through SPV installation.
4. SPV installation in waste/barren lands supports decentralized electricity generation and enables multi utilization of the area for activities such as grazing, livestock farming, etc. About 45 million households are still not electrified in India, which have potential to generate enough electricity from rooftop SPV installation; rooftop SPV installation would be the revolutionary method of rural electrification.
5. Rooftop SPV installation is the most adoptable technology in highly populous countries like India, where the monthly electricity consumption of a household ranges from 50 to 100 kWh. Encouragement for roof top SPV based electricity generation rather than centralized generation through incentives, financial aid for initial installation and tax holidays.

Supply of electricity to households in remote areas entails investment on infrastructure apart from transmission and distribution (T&D) loss of electricity. Assessment reveals that T&D loss in Karnataka is about 19.5% resulting in the loss of 7,210.16 GWh (annual demand is 36,975.2 GWh in 2010-11) of energy. Cost of energy loss ranges from Rs. 1,514.13 crores (@ Rs. 2.10/kWh) to Rs. 5,047.11 crores (@ Rs. 7/kWh) depending upon the tariff (in the respective state).

Decentralized generation of electricity through SPV would help in meeting the respective household's electricity demand apart from the removal of T&D losses. Generation based incentives (GBI) would herald the decentralized electricity generation, which would help in boosting the regional economy. Considering the current level of T & D losses in centralized system, inefficient and unreliable electricity supply, it is necessary to promote decentralized energy generation. Small capacity systems are efficient, economical and more importantly would meet the local electricity demand. The incentive could be

- Rs. 4.00 per unit for first five years (comparable to **subsidies granted to mini hydel projects, the power purchase at Rs 3.40)** and Rs. 3.50 for the next two years for the electricity generated from roof top solar PV.
- Buyback programmes for the electricity generated at household level and in micro grid - GBI of Rs. 5 to be provided for electricity generation (< 5 kW) feeding to the grid by SPV.
- Free solar home lighting (with LED lamps) under the Chief Minister's Solar Powered Green House Scheme (CMSPGHS), Government of Karnataka or JNNSM (Jawaharlal Nehru National Solar Mission, Government of India).
- All street lights and water Supply installations in local bodies to be energized through solar power (or hybrid mechanism) in a phased manner
- Install solar rooftops in all new government/local body buildings - implementation of solar rooftops could be in a phased manner in the existing government/local body buildings, etc.
- Exemption from payment of electricity tax to the extent of 100% on electricity generated from solar power projects used for self-consumption/sale to utility to be allowed for at least10 years.
- Fixing of standards for quality installation.

6. Commercial lighting in advertisement boards should only be from SPV panels. Complete ban on usage of grid electricity for these purposes.
7. Impetus to energy research through generous funding for the R and D activities to ensure further improvements in the grid, technologies, two way communication energy meters

(to connect rooftop generation with existing grid), efficient luminaries' production, low cost wiring, switchgears, appliances, etc.

8. Energy education (focusing mainly on renewable energy technologies, end-use energy efficiency improvements, energy conservation) at all levels. School curriculum shall include renewable energy (RE) concepts.
9. Awareness about energy independence and the necessity of RE sources in the present gloomy energy scenario to the consumers
10. Education and awareness about applications and importance of renewable energy sources.
11. Capacity building of youth through technical education for installation and servicing of SPV panels.
12. Diploma /ITI courses with hand-on training on renewable energy technologies in all taluks
13. Setting up service centers in block development offices to meet the requirement of service support for RE technologies (Solar, biogas, energy efficient chulas, etc.).
14. Periodic revision of FIT structure and incentives to encourage the consumers.
15. Mandatory one week capacity building / training programmes to all bureaucrats and energy professionals at the initial stages of the career. This is essential as lack of awareness/knowledge among the bureaucrats is the major hurdle for successful dissemination of renewable energy technologies in India

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APPENDIX I:

Sampled regions

Zone	Taluk	Region (Village/town)	Pop	H	Pop /H	R (m^2)	R/H (sq.m)	R/pop (m^2)	B (m^2)	R/B
Coastal	Bhatkal	Golibilur	506	74	7	4712	64	9	15174	0.31
	Bhatkal	Karikal	880	165	5	10040	61	11	23249	0.43
	Honnavar	Madageri	590	121	5	11460	95	19	15399	0.74
	Karwar	Hosali	610	152	4	10770	71	18	98246	0.11
	Kumta	Lukkeri	1791	280	6	19420	69	11	74672	0.26
		Average					**72**			**0.37**
Dry deciduous	Mundgod	Lakolli	590	116	5	12740	110	22	21896	0.58
	Haliyal	Chibbalgeri	748	126	6	21150	168	28	27470	0.77
	Haliyal	Bidroli	725	137	5	20080	147	28	97171	0.21
		Average					**141**			**0.52**
Evergreen	Honnavar	Hosgod	229	40	6	6475	162	28	4525	1.43
	Honnavar	Dabbod	392	79	5	9629	122	25	15824	0.61
	Ankola	Brahmur	594	114	5	13330	117	22	4625	2.88
	Ankola	Karebail	191	42	5	3848	92	20	1425	2.70
	Karwar	Shirve	374	75	5	10730	143	29	5175	2.07
	Sirsi	Somanalli	198	37	5	9147	247	46	1400	

	Sirsi	Dhoranagiri	302	62	5	13010	210	43	1075	
	Sirsi	Onigadde	348	63	6	10050	160	29	6825	1.47
	Supa	Vatala	245	45	5	6337	141	26	1200	
	Supa	Nandigadde	387	107	4	8912	83	23	5790	1.54
	Supa	Boregali	193	35	6	5590	160	29	750	
	Supa	Viral	91	16	6	2199	137	24	625	
	Supa	Kunagini	95	20	5	2398	120	25	250	
	Supa	Godashet	358	73	5	6270	86	18	5675	1.10
	Siddapur	Halehalla	195	37	5	4612	125	24	100	
	Siddapur	Golikai	332	67	5	9032	135	27	1225	
	Yellapur	Kelashi	245	52	5	8522	164	35	37099	0.23
	Yellapur	Beegar	231	42	6	4432	106	19	2475	1.79
		Average					**139**			**1.58**
Moist deciduous	Mundgod	Chalgeri	455	83	5	6617	80	15	42473	0.16
	Haliyal	Dandeli	53290	11121	5	894200	80	17	2176694	0.41
	Sirsi	Sahasralli	207	40	5	3671	92	18	22099	0.17
	Supa	Kondapa	281	69	4	5212	76	19	4900	1.06
		Average					**82**			**0.45**

Prospects of Bioenergy in Uttara Kannada district

SUMMARY

Rural population of India mostly depends on bio energy for cooking, space and water heating. Though most of the energy need is harvested from fossil fuels, 70% of the rural population depends on the bio energy for their domestic usage in the country. About 70% of the Indian population lives in rural area where 75% of the primary energy need is supplied by bio energy resources. Also, about 22% of the urban households depend on firewood, 22% on kerosene and 44% on LPG for cooking in the country. Bio energy resources are renewable in nature and combustion would not produce poisonous gases and ash with sufficient oxygen supply. A village level study on the present scenario of domestic energy consumption will help to assess the demand and supply of bio energy in the country. Uttara Kannada district in Karnataka state, India is chosen for bio energy assessment which has evergreen as well as moist and dry deciduous forest. In the district majority of the people live in rural area or in semi urban area, mostly dependent on forest, agricultural and livestock residues for domestic energy need.

Bioresource 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 Organisation (NSSO study) data, primary survey data and from the literature. Using the data of bioresource availability and demand, bioresource status is computed for all the agroclimatic zones. The ratio of bioresource availability to demand gives the bioresource status. The ratio greater than one indicates bioresource surplus zones, while a ratio less than one indicates scarcity. The supply/demand ratio in the district ranges from less than 0.5 to more the 2. If the ratio is less than 1 (demand > supply) then that place is fuel wood deficit place and where the ratio is more than 1 (supply > demand) then that place is referred as fuel wood surplus region. In Uttara Kannada, most of the Taluks with ever green forest cover (Sirsi, Siddapur, Yellapur, Supa and estern hilly ares of Kumta, Honnavar and Ankola) are fuel wood surplus regions where the supply/demand ratio is currently > 2 (compared to 8-9 in early 1990's). Dwindling resource base could be attributed to the decline in forest cover in the district.

KEYWORDS: Total primary energy supply (TPES), Bio energy, BETs, Municipal solid waste (MSW), forest residues

1. INTRODUCTION

Energy is the fundamental need of human beings with air, water, shelter and food (energy). In ancient time energy used by human was about 2,500 kJ per day. After the invention of fire and other energy harvesting methods from sun, water and wind, energy usage has been increased to 30,000 kJ per day. In the present day, energy used by humans is more than 2 lakh kJ every day [1]. As the energy demand has increased, exploitation of resources to produce energy is also increased and the fossil fuels hold the major share in generating energy. In India, more than 70% of the total primary energy supply (TPES) is supplied from non-renewable energy sources (coal, crude oil or natural gas) and around 20% is from hydro resources. Only about 10% of the energy basket is supplied by renewable energy sources which include solar, wind, geothermal, tidal etc [2]. Though most of the energy need is harvested from fossil fuels, 70% of the rural population depends on the bio energy for their domestic usage in the country.

Bio energy refers to the energy released when organic carbon reacts with oxygen. This energy may be harvested from plants or animals which are also called as biomass. During the process of photosynthesis some energy will be trapped and stored in the form of organic carbon in plants from which energy can be extracted through burning. Bio mass is the most processed energy form of carbon and used as primary energy which can substitute the non renewable energy sources [3]. Bio energy resources combine fuel wood from forest, biogas, bagasse, agricultural residues, livestock residues, feedstock residues, solid waste etc.

Bioenergy plays a prominent role in country's economy and an important component of TPES. Technical analysis of the bio energy technologies (BET) would help to understand the recent developments and the need for the further research in the respective area. Various advantages of BETs open the ways for numerous application and developments in the technology. Cost of energy harvesting technology and the energy source is an important factor of consideration for its feasibility to common man. Bio energy is an in-exhaustive source, freely available in most of the situations (or very inexpensive). BETs mainly use the residues (byproducts) of forest, agriculture, horticulture etc. and animal waste which are abundantly available in rural areas. Municipal Solid Waste (MSW) is a major source for bioenergy in urban areas, which will reduce the associated difficulties such as waste disposal, pollution etc. Biomass based power generation system requires less capital cost compare to other technologies since land, infrastructure and technology requirements are less expensive. However bio energy utilization is techno-economically feasible and contributes significantly to the economic growth of the country.

About 70% of the Indian population lives in rural area where 75% of the primary energy need is supplied by bio energy resources. About 75% of the rural households depend on firewood, 10% on dung cake and 5% on LPG for cooking and 22% of the urban households depend on firewood, 22% on kerosene and 44% on LPG for cooking in the country [4]. About 1,50,000 households in the country yet to be electrified and more than 400 million people do not have access to electricity [5]. In electrified villages also the electricity supply is not reliable and load shedding is often. About 50% of the rural households depend on kerosene and 48% of the households depend on electricity for lighting. Hence most of the Indian population is either dependent on fossil fuel or bio energy for their daily cooking, water heating and lighting. The above discussion is evident that bio energy can contribute significantly to the sustainable development and to the country's economy [6].

1.1 Present Bio-energy status in India: India is the 4th most energy producing country in the world with a population share of 17.5% of the world's population. As the population increased, the energy requirement also increased over the years which led to exploitation of resources at a higher rate. Per capita Total Primary Energy Supply (TPES) in India was about 540 kgoe (kilogram oil equivalent) in 2010 and World average was 1803 kgoe [7]. Coal and peat are the major contributors to the TPES with a share of 42.30% followed by crude oil (23.60%) and natural gas (7.20%). Combustible Renewable and waste (CRW) are the 2nd prominent source of TPES with a share of 25%. Figure 1 (a) gives the percentage shares of energy sources in total primary energy supply in India. Residential sector gets around 78% of the energy from CRW sources followed by Industries (17.40%) [8]. Figure 1 (b) gives the sector wise usage of CRW in the country.

Figure 1 (b) clearly shows that major part of the domestic energy consumption is supplied by the combustible renewable or bio energy. Hence bio energy plays a vital role in feeding domestic energy demand of India.

Energy demand is in direct relation with population, demand increases with the population. Total primary energy demand in India was 117.2 Mtoe in 1960-61 and around 5.2% of the total demand was imported. Per capita energy demand was 266.82 kgoe in 1961 while the total population was about 43.9 crores. Total primary energy demand increased to twice in 45 years which is 539 Mtoe in 2007. Population in 2007 was 112.9 crores and per capita energy demand is about 477.12 kgoe [9]. About 15.5% of the total energy is being imported in the present day where the total demand has crossed 715 Mtoe [10]. Table 1 gives the trends in demand and supply of primary energy in India from 1960-61 to 2011-12. It also shows the increase in population for the same duration.

Table 1: Trends in demand and supply of primary energy (Mtoe)

Year	Population (Million)	TPES (Mtoe)	Net Imports (Mtoe)	% Imports
1960-61	439.23	117.2	6.04	5.15
1970-71	547.90	147.05	12.66	8.61
1980-81	685.20	208.3	24.63	11.82
1990-91	843.93	303.15	31.07	10.25
2000-01	1027	432.75	89.03	20.57
2006-07	1130	539.09	131.97	24.48
2007-08	1158	617.52	154.38	25.00
2008-09	1174	656.27	164.07	25.00
2009-10	1190	673.84	168.46	25.00
2010-11	1220	715	111	15.52

(Source: http://data.worldbank.org/country/india)

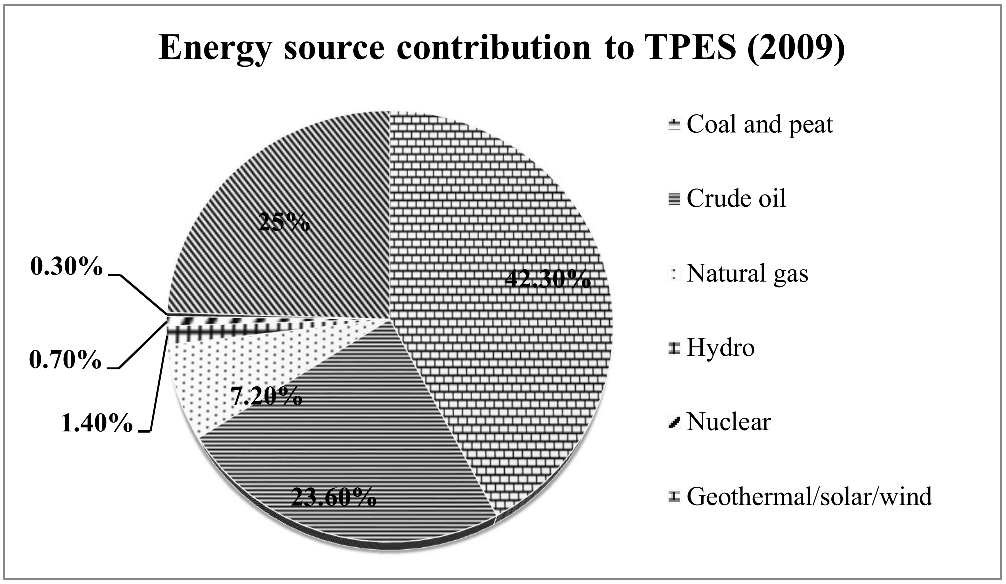

Figure 1 (a): Share of energy sources in TPES

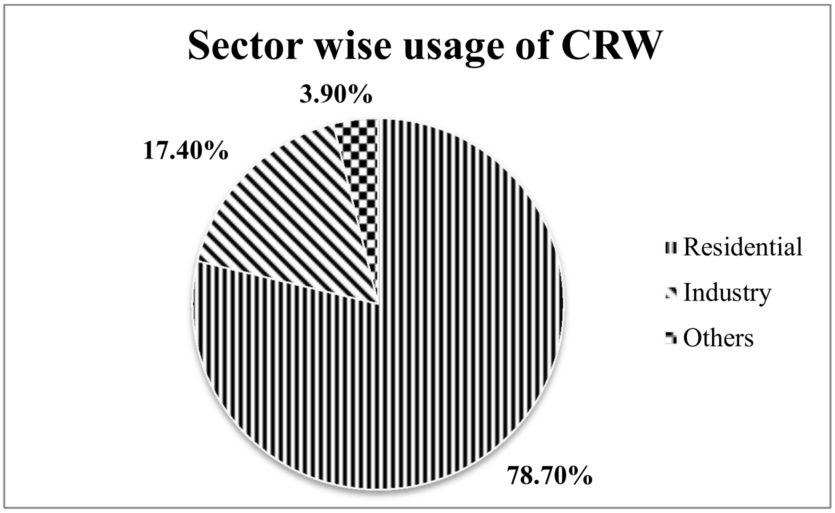

Figure 1 (b): Sector wise share of CRW

Energy generation in the country depends mostly on fossil fuels which are limited in nature. Since India has less fossil fuel resources and these resources should be conserved for the future generation, the country is importing significant amount of petroleum oil, nuclear energy resources, coal, natural gas etc. This trade is affecting the economical growth of the country and also more and more fossil fuel extraction has adverse effects on sustainable development [11]. Burning of fossil fuels emits enormous amount of carbon dioxide (CO_2) and other gases (CO,

SO_2 or nuclear waste) which are the root cause for all global and ecological problems. However renewable energy applications have negligible carbon dioxide emission and eco-friendly. About 25% of the primary energy demand is supplied by combustible renewable and wastes in India, where most of the rural population depends on bio energy [12].

Rural population of India mostly depends on bio energy for cooking, space and water heating. About 75% of the energy demand is supplied by bio energy in rural areas of the country where 70% of the total population live. The bio energy use in the country is showing a decreasing trend over the years due to urbanization and rural electrification; nevertheless at present about 25% of the energy demand is met by bio energy. More than 50% of the primary energy demand was supplied by bio energy in 1983 which is about 25% in 2010 [13]. Table 1 gives the share of bio energy in total primary energy supplies (TPES) from 1983 to 2010.

Bio energy has a significant share in the TPES which effects the total energy generation of the country. Since energy independence or the per capita energy consumption is one of the prominent factor to decide country's development, bio energy is also has a significant effect on developmental issues. Other important aspect associated with energy generation is regarding environmental pollution and waste disposal. Bio energy resources are renewable in nature and combustion would not produce poisonous gases and ash with sufficient oxygen supply. However the CO_2 generated during combustion of bio energy will be used by plants in the process of photosynthesis. Hence the ecological balance is not disturbed by using bio energy [14]. This process leads to forestation which is the important part of ecological system to maintain the balance and to promote sustainability. Table 2 gives the share of Combustible Renewable and Waste (CRW) in TPES for the duration 1983 to 2010 in the country.

Table 2: Share of CRW in TPES for the duration of 1983-2010

Year	Share or CRW in TPES (%)	Year	Share or CRW in TPES (%)
1983	52.3	1997	34.6
1984	50.8	1998	34.2
1985	48.9	1999	32.7
1986	47.6	2000	32.6
1987	46.7	2001	32.5
1988	44.9	2002	32.0
1989	43.4	2003	31.5
1990	42.1	2004	30.2
1991	41.1	2005	29.5
1992	40.0	2006	28.4
1993	39.3	2007	27.3
1994	38.1	2008	26.5
1995	36.4	2009	24.9
1996	35.6	2010	24.6

(Source: The World Bank Data)

A village level study on the present scenario of domestic energy consumption will help to assess the demand and supply of bio energy in the country. For bio energy assessment Uttara Kannada district in Karnataka state, India is chosen which has evergreen as well as moist and dry deciduous forest. In the district majority of the people live in rural area or in semi urban area, mostly dependent on forest, agricultural and livestock residues for domestic energy need.

2. OBJECTIVES

The primary objective of the study is to assess the bio energy status in Uttara Kannada district across the agroclimatic zones. This includes:

1. Identifying the bioenergy surplus and deficit places in the district
2. Techno-economic analysis of bio energy applications and
3. The role of bio energy in sustainable development.

3. MATERIALS AND METHOD

3.1 Study Area: Uttara Kannada district is located between 13° 55′ and 15° 31′ latitudes and 74° 9′ and 75° 10′ longitudes (figure 3). It is the 4th biggest district of the state having population of 14,36,847, with more than 70% of the people live in rural area or in semi urban area. District is located in central Western Ghats with rich ecology. More than 75% of the total area is forest covered and has 140 km costal belt [14].

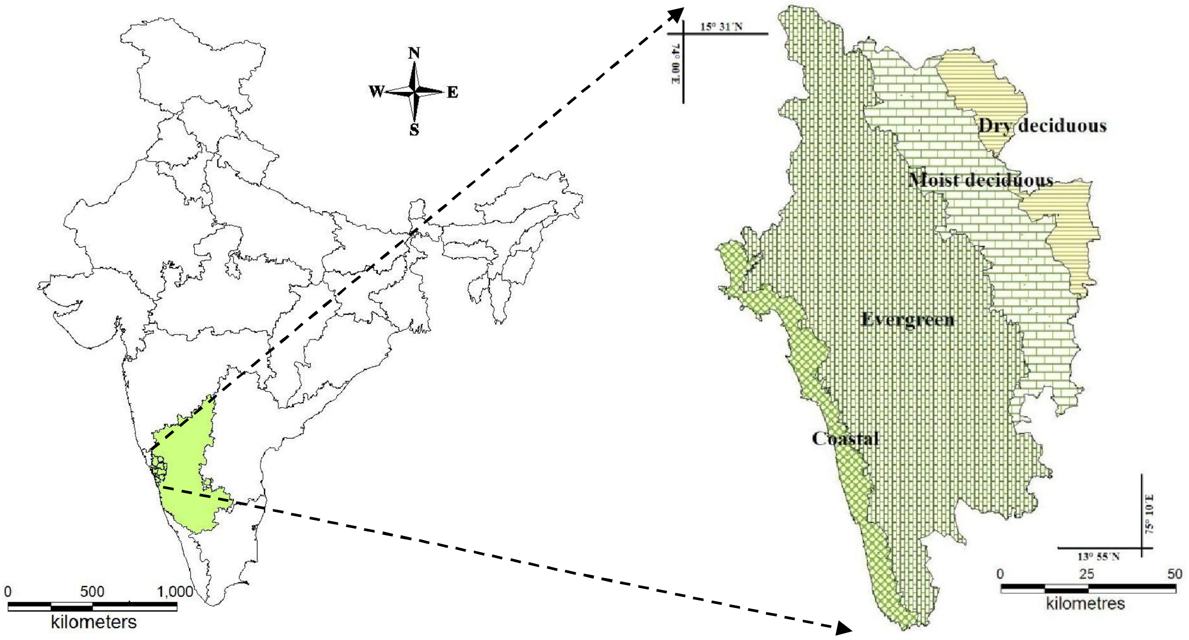

Figure 3 (a)

Figure 3 (b)

The geographical heterogeneity is responsible for the diverse growth of vegetation in the district. Taluks of the district are categorized under 4 different types of forests which are

- Ever green forests normally found in Sirsi, Siddapur and eastern hilly regions of Honnavar, Kumta and Ankola Taluks.
- Semi Deciduous forest, found in slopes of Ankola, Kumta, Karwar, Honnavar, Siddapur and Sirsi.
- Deciduous forests are mostly found in Haliyal, Supa and Mundgod region.
- Forest in the coastal region, normally found in Kumta, Honnavar, Ankola, Karwar and Bhatkal region.

Figure 3 (a) gives the location of the study and Figure 3 (b) gives the climatic zones and forest types of Uttara Kannada. Extent of the forest cover and type of forest has a major effect on bio energy supply. Evergreen forest found in most of the places in the central region followed by moist and dry deciduous forests [15].

3.2 Method and Data: Bioenergy status assessment is done based on the resource availability and bio energy requirement in the district. Having the knowledge of current bioenergy usage pattern in different agroclimatic zones, demand for bioenergy is computed. Bioresourse is mainly depends on the land use pattern, forest cover and yields of various crops. Using the earlier energy survey data and by spatio temporal land use dynamics analysis availability of resources and corresponding demands are calculated. All the estimations are done taluk wise and aggregated for each agroclimatic zone.

3.3 LULC dynamics of Uttara Kannada: Forest resources constitute the primary source of energy in the district. The analysis of land use dynamics during 1979 to 2013 shows that about 75.88% of area under evergreen forest (1979) has declined 53% in 2013. Areas under agriculture land and forest plantations have increased from 10.22% and 7.79% to 14.13% and 18.64% respectively. Figure 4 gives the percentage change in LULC pattern in the district from 1979 to 2013.

Table 3 gives the land use variation and area under different land use category from 1979 to 2013.

Table 3: Land use variations from 1973 to 2010

Category		**1979**	**%**	**1989**	**%**	**1999**	**%**	**2013**	**%**
Built-up		9,738	0.95	12,982	1.26	21,635	2.1	31,559	3.07
Water		18,527	1.8	16,604	1.61	32,983	3.21	28,113	2.73
Agriculture land		1,03,163	10.02	1,21,167	11.77	1,38,458	13.45	1,45,395	14.13
Open land		15,988	1.55	34,783	3.38	21,945	2.13	37,660	3.66
Horticulture land		20,675	2.01	32,227	3.13	43,623	4.24	48,993	4.76
Forest	Teak /	0	0	21,937	2.13	38,588	3.75	67,911	6.6

Plantation	Bamboo / other Softwood								
	Acacia / Eucalyptus / Other Hardwood	80,217	7.79	55,694	5.41	73,977	7.19	1,23,927	12.04
	Total	**80,217**	**7.79**	**77,631**	**7.54**	**1,12,565**	**10.94**	**1,91,838**	**18.64**
Forest	Moist deciduous forest	1,02,967	10.01	1,43,849	13.98	1,79,075	17.4	1,64,996	16.03
	Evergreen to semi evergreen forest	5,89,762	57.31	5,31,872	51.68	4,23,062	41.11	3,30,257	32.09
	Scrub/grass lands	58,936	5.73	44,123	4.29	47,366	4.6	40,402	3.93
	Dry deciduous Forest	29,113	2.83	13,848	1.35	8,374	0.81	9,873	0.96
	Total	**7,80,778**	**75.88**	**7,33,692**	**71.3**	**6,57,877**	**63.92**	**5,45,528**	**53.01**
Total		**10,29,086**	**100**	**10,29,086**	**100**	**10,29,086**	**100**	**10,29,086**	**100**

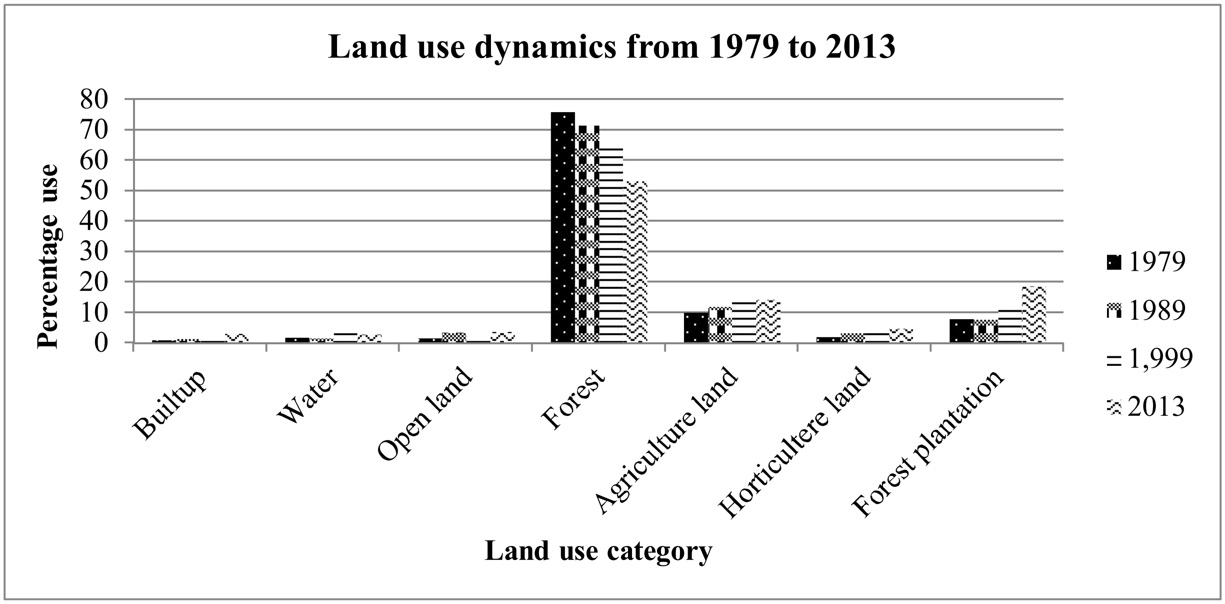

Figure 4: Spatio temporal land use dynamics

Change in forest cover and other land use classes are given in Figure 5. It is evident that forest cover decreased and built up area and crop lands have increased over the years.

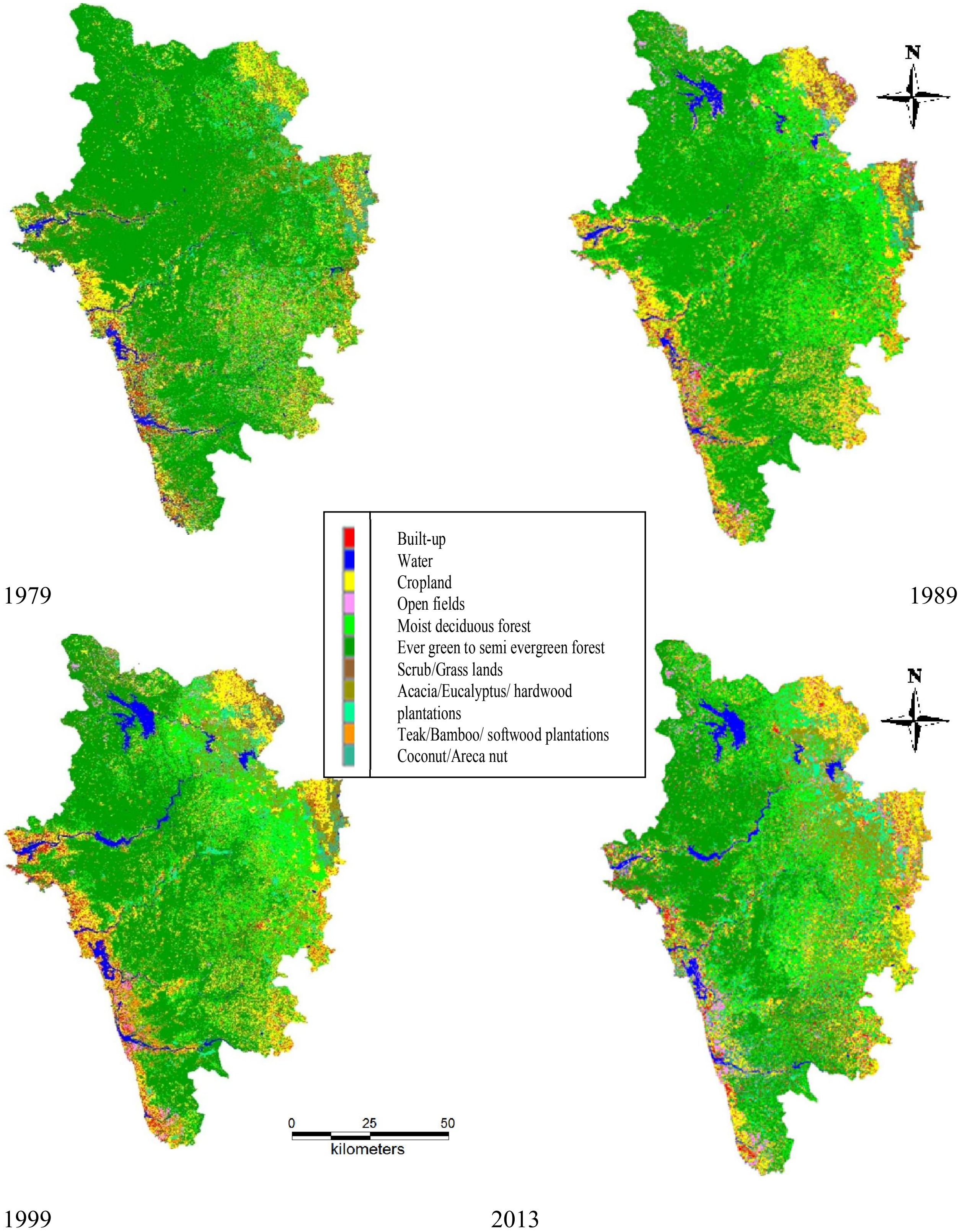

Figure 5: Land use dynamics of Uttara Kannada

4. RESULTS AND DISCUSSION

Bio resources from various sources (forests, agriculture, horticulture) is used for domestic applications (cooking, water heating) in the district. Fuel wood is mainly used for domestic cooking and water heating supplemented by horticultural and agricultural residues, forest biomass and biogas production from livestock. Majority of the fuel requirement for cooking, water and space heating is supplied by agricultural residues, animal matter or by forest in the district. More than 80% of the people are dependent on bio energy for their requirements such as food, fuel wood for traditional stoves, timber for houses and cattle sheds, poles for fencing and shelter construction, leaves to prepare manure and covering to control weed, wood to prepare all housing structures, ropes, herbal medicines and decorative articles [16]. Study gives the village level details of supply and demand trend of bio energy in the district.

4.1 Supply and Demand trends of Bio energy in Uttara Kannada

4.1.1 Fuel wood: Fuel wood is one of the prominent forest by-products collected (normally by women and children) which is used for cooking and water heating through burning. Major domestic energy need is shared by fuel wood in the rural regions where the people collect it from nearby forest. The availability of the fuel wood for the consumers is depends on the closeness of the forest, type of the forest and methods of extraction. Figure 6 gives the availability of fuel wood in the districts annually. Since fuel wood is the cheapest primary energy source hence the demand will be high depending upon the availability. If the demand for the fuel wood increases then it may lead to deforestation or consumers may switch over to some other fuels such as LPG, electricity or kerosene due to the lack of availability. The annual fuel wood availability in the district ranges from less than 1,000 tonnes to 56.000 tonnes. In majority of the villages of Sirsi, Siddapur, Kumta and Honnavar Taluks, availability of fuel food ranges from 1,000 to 5,000 tonnes per annum. In northern villages of Haliyal and Supa Taluks availability of forest bio mass per annum is less than 1,000 tonnes to 5,000 tonnes. Availability of fuel wood is high in the central region of the district. In eastern part of Karwar and Ankola and southern part of Supa fuel wood availableness is 10,000 to 25,000 tonnes per annum. There are few villages Supa and Yellapur Taluks where the bio-mass availability is 25,000 to 56,000 tonnes in a year.

Figure 7 gives the supply to demand ratio of available forest bio mass (fuel wood) in the district. The supply/demand ratio in the district ranges from less than 0.5 to more the 2. If the ratio is less than 1 (supply < demand) then that place is fuel wood deficit place and where the ratio is more than 1 (supply > demand) then that place is fuel wood surplus region. In Uttara Kannada, most of the Taluks with ever green forest cover (Sirsi, Siddapur, Yellapur, Supa and estern hilly ares of Kumta, Honnavar and Ankola) are fuel wood surplus regions where the supply/demand ratio is more than 2. The villages with semi and moist deciduous forests (Western parts of Mundgod and Haliyal, Eastern parts of Bhatkal and Karwar) are also forest bio mass surplus places where the availability ratio is more than 1. The coastal and the extreme eastern part of the district (coastal villages of Karwar, Ankola, Kumta, Honnavar and Bhatkal with eastern part of Mundgod and

Haliyal) are the fuel wood deficit places. The bioresource supply is dwindling in the district evident from the reduced bioresource supply to demand ratio from 8-9 [15] to 2. This necessitates sustainable management approaches with augmentation of forest resources.

4.1.2 Bio-energy from Agricultural residues: Agricultural crops grown in the district include rice, ragi, jowar, bajra, maize and wheat. Paddy is the major crop in the district followed by jowar and maize. Net sown area in the district is about 1,12,946 ha which includes cereals, commercial crops and oilseeds.

a. Paddy residues: Paddy (Oryza sativa) is the widely grown crop in the district (78,073 ha, 69.12%). Rice husk and stalk are major constituents of the residue from paddy cultivation. The average higher calorific value of rice husk ranges from 2937.5 to 3461.31 kcals and lower value is from 2637.2 9 to 3161.2 5 kcals. The stalk is mainly used as fodder and husk is the main energy component in the residue.

b. Maize residues: Maize is one of the prominent crops in the district with a share of 3.68% of net sown area. Maize cobs are major residues from the crop which constitute about 30% of maize gain (Zea mays). Cobs are used to feed cattle or as fuel.

c. Bagasse: Sugarcane is an important cash crop in the district which is mainly used to prepare jaggery. Area used to grow sugarcane in the district is about 1,232 ha (1.09% of total sown area). Bagasse is a major residue from sugarcane which is left after extracting juice from it. The fibrous content in the sugarcane is the major contributor to the bagasse which is normally in the range of 30-32%. Bagasse is used as a fuel with wood in the process of producing jaggery from sugarcane juice which has a calorific value of 3500 kcals. Bagasse is also used to generate methane gas; 1 tonne of bagasse generates about 20 m^3 of combustible methane gas.

d. Oil seed: Ground nut is the most important and widely grown oil seed crop in the district followed by cotton. Ground nut is grown in 2949 ha (2.61%) where the total oil seed growing area is 3177 ha (2.81%). Sun flower is the other oil seed crop which is grown in the district (228 ha). About 1,878 ha (1.66% of net sown area) of area is under cotton which produces oil seeds. About 30% of the ground nut pod consists of shell which is used as residue has an average higher calorific value of about 4532.15 kcal/kg and the lower calorific value of about 4248.5 8 kcal/kg [17,18].

Figure 8 gives the annual energy available from agricultural residues in the district, which ranges from 250 million kWh to 90,000 million kWh per year. In majority of the villages (895 villages) of Yellapur, Supa, Siddapur, Sirsi and Kumta Taluks energy availability from agricultural residues is less than 250 million kWh per year. Some villages in Ankola, Sirsi, Siddapur and Haliyal Taluks get the annual energy from agricultural residues about 250 to 500 millon kWh. Similarly, some villages in Karwar, Ankola and Haliyal Taluks have annual energy from agri-residues of 500 to 2,000 million kWh. In very few villages in the district (Mundgod taluk), energy from agricultural residues is more than 10,000 million kWh per year and the maximum availability is about 90,000 million kWh per annum.

4.1.3 Bio energy from Horticulture: Plantation crops (cash crops) such as areca (Areca catechu), coconut (Cocos nucifera), cashew (Anacardium occidentale), banana (Musa accuminata), cardamom (Elletaria cardamomum), cocoa (Theobroma cacao), pepper and spices are the major crops (32,953 ha, 29%) next to paddy in the district. There is an increasing trend in growing these crops in the district due to their commercial value. Coastal belt takes the major share in growing coconut crop and areca is grown in almost all the taluks. Area under areca crop is increasing with a higher rate in recent years which has become the crop of major income in Kumta, Honnavar, Ankola, Sirsi, Siddapur and part of Yellapur taluks. Cashew is a seasonal bearing plant which is normally grown in hilly or in waste land in the district. Cardamom, cocoa tree and spices are grown with areca and coconut plantations (1,675 ha) in the district which have higher trade value in the market. Horticulture crops are also the important source of residues which mainly contains combustible bio mass.

Horticulture residues

a. Areca residues

   Areca is the most growing crop after paddy in the district. Fuel biomass extracted from areca is leaves, inflorescence, and husk and leaf sheath. Areca husk is the outer cover of areca fruit which accounts for 60-80% of the total volume (fresh weight consideration) [19]. It is normally used to cover the field or as mulch rather than used as fuel. It can be used in the manufacture of card boards, paper boards etc and properly composted husk can be good organic manure [20]. On average 5-6 leaves can be obtained from each areca tree per year. It is used to prepare manure, to cover edges of cannels agricultural land, as fuel bio mass and to feed cattle. Used and throw (single use) plates and cups, hats and other decorative items manufactured by sheaths are getting attention of people in the district and state wide.

   Areca leaves are used as thatching materials and to cover areca gardens. These are the good source of manure and also combustible bio mass. Other residues such as inflorescence and trunk of the tree are used as fuel. Trunk is mainly used for construction and when it dries and become strength less it will be used as fuel.

b. Coconut residues

   Coconut residues are mainly used for combustion (fuel bio mass) which are leaves, inflorescence, shells, husk and leaf sheath. Coconut husk is widely used for making coir, mats, rope and also used to cover coconut plantations [21]. It is dried and used as main fuel for water heating during rainy season in the district. Shells are mainly used as fuel which has higher combustion value. Coconut shell charcoal production is gaining importance since it has a market value. Leave of coconut palms are used to cover houses and other plantation fields. Leaves are used to produce groom sticks which can be trade in the market [22].

c. Other residues

Other residues generated from horticulture crops are due to cashew cocoa and banana plantation. Cashew is one of widely grown cash crop in Uttara Kannada. Cashew shell husk is the major residue from the crop followed by the fuel wood from tree branches. Cocoa tree is sparsely grown in the district from which fuel wood and leaves are extracted as residues. Main Residue of banana plantation is leaves which are used instead of plates for serving the food and in cooking; also leaves are used to cover the plantation. However the banana tree will not produce any combustible residues.

Figure 9 gives the annual energy availability from horticultural residues in the district. In many taluks in the district namely Sirsi, Siddapur, Yellaour, Haliyal, Mundgod and Supa the annual availability of energy from horticultural residues is less than 250 million kWh per annum. Few villages (126) in the eastern part of Ankola taluk have 250 to 500 million kWh. In some villages of Honnavar and Karwar taluks, annual energy availability from horticultural residues ranges from 500 to 2,000 million kWh. Very few villages in the district have availability of energy from horticultural residues more than 10,000 million kWh.

Figure 10 gives the combined annual energy availability from agriculture and horticulture residues. In majority of the villages annual energy availability is less than 250 million kWh per annum. There are some villages in the district where energy availability rages from 250 to 500 million kWh (155 villages) and 500 to 2,000 million kWh (225 villages). In 159 villages of eastern part of Ankola, Mondgod and Haliyal energy from horticulture and agri residues in the range 2,000 to 10,000 million kWh. In nine villages, available energy is more than 10,000 million kWh which extends up to 90,000 million kWh.

4.1.4 Biogas resource status: Livestock a vital component of agrarian ecosystem, provides milk and manure. Other uses of livestock are for wool, for meat, transportation and for ploughing (or sowing). Animal residue from livestock aid in recharging the essential nutrients of soil. It also boosts the quality of the organic manure which increases the soil fertility.

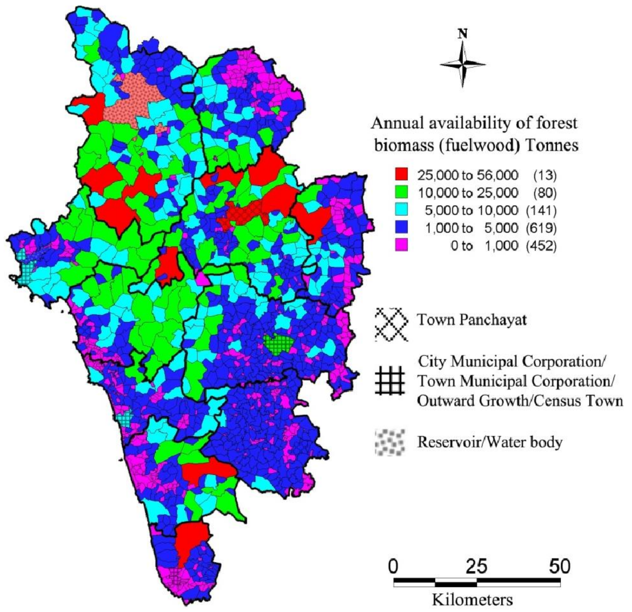

Figure 6: Availability of forest biomass (fuel wood) in tonnes/annum

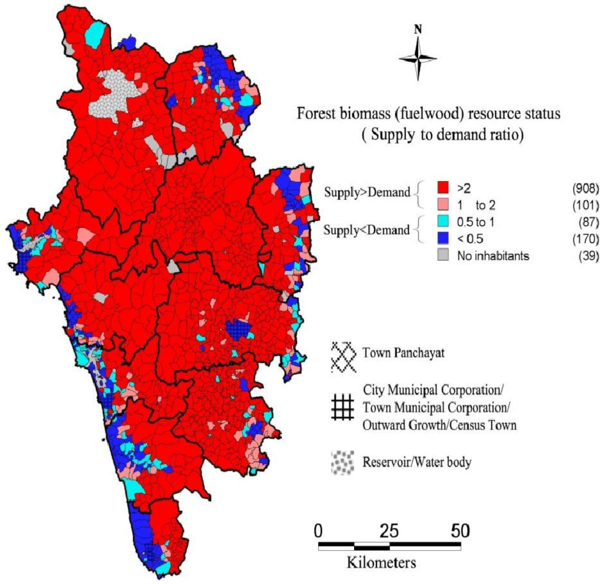

Figure 7: Fuel wood resource status (Supply to demand ratio)

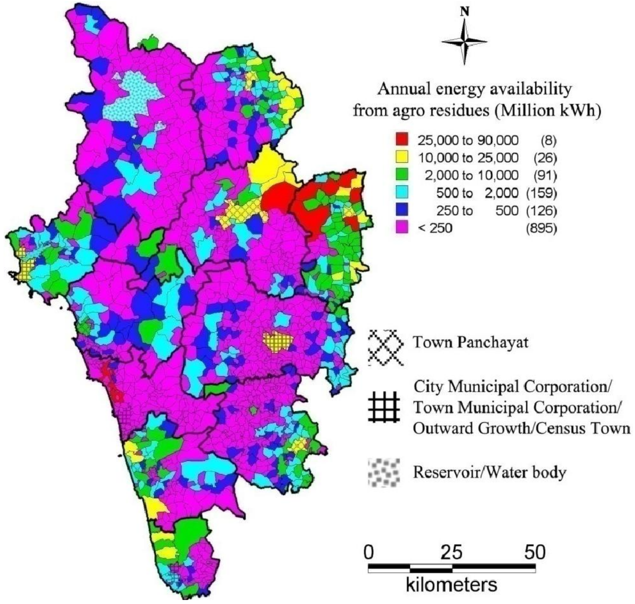

Figure 8: energy from agricultural residues

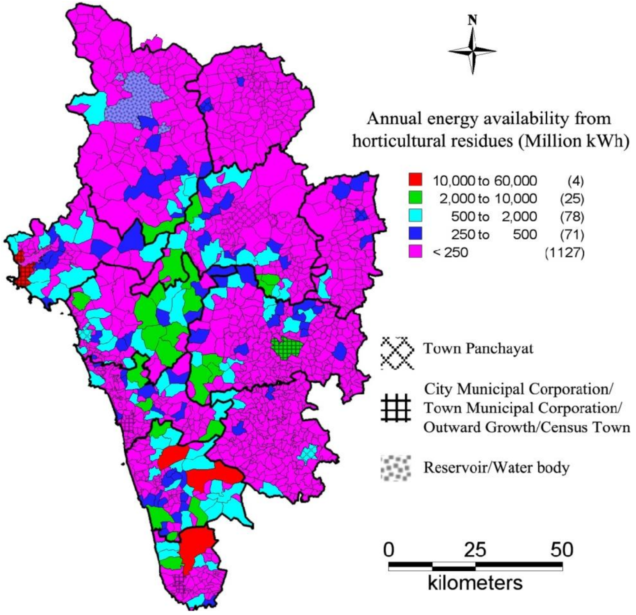

Figure 9: energy from horticultural residues

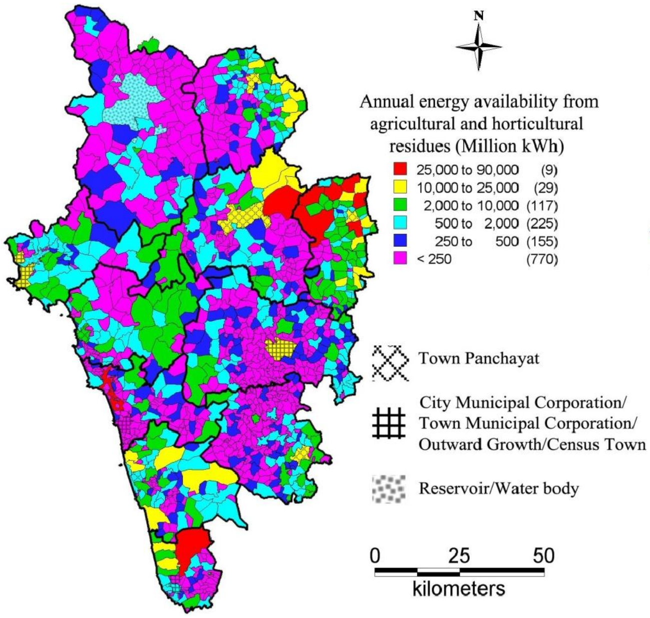

Figure 10: Annual energy availability from agricultural and horticultural residues

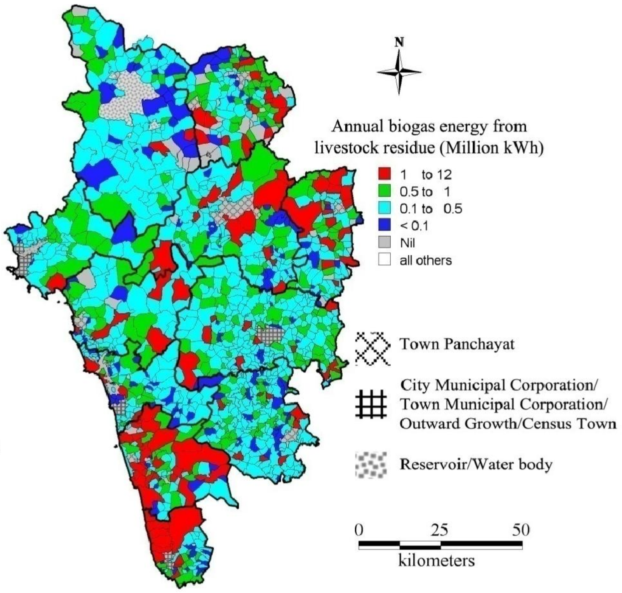

Figure 11: Annual biogas production from livestock residues in Uttara Kannada

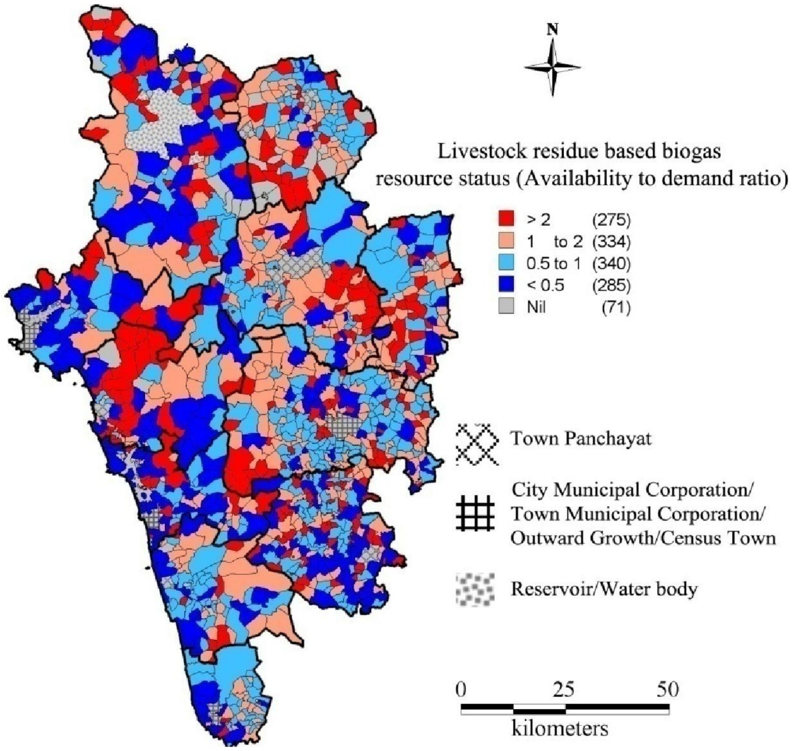

Figure 12: Biogas resource status (supply to demand ratio)

Farmers in Uttara Kannada are very much dependent on livestock for their agriculture and horticulture practices. Animal residue is the main feedstock for the production of biogas as well as manure. There are about 3,66,949 cattle, 1,18,669 Buffaloes, 2,702 Sheep, 11,994 Goats in Uttara Kannada. Other members of livestock are Pigs (900), Dogs (93,403) and Rabbits (277).

Total livestock population in the district is about 5,94,929 and poultry population is 3,61,351. Dung available from each cattle varies from 3-4 kg to 8-10 kg (from coastal to hilly region). Similarly average dung produced from a buffalo is 12-15 kg and from a hybrid one is 15-18 kg. By considering 3 kg dung production from a cattle in coastal area and 8 kg in hilly area, total dung production from cattle is about 6,32,058.46 tonnes per year. Similarly by considering the dung production per buffalo as 12 kg/day, total dung obtained is 5,19,770.22 tonnes per year. Assuming gas production of 0.036 m^3 per kg of dung, total biogas generated will be 41,465 thousand m^3 per year [23, 24]. National per capita natural gas consumption is about 54 m^3 per annum; then the biogas produced from livestock residue could meet the 50% of the gas demand in Uttara Kannada district [25]. (100% dung produced is considered to generate biogas). Table 4 gives the Taluk wise livestock population with annual dung and biogas production in the district.

Table 4: Taluk wise dung and biogas production in Uttara Kannada

Taluk	Cattle population	Dung Prod./day (kg)	Dung Prod./yr (tonnes)	Buffalo population	Dung Prod./day (kg)	Dung Prod./yr (tonnes)	Total biogas production (*1000 m^3)
Ankola	28570	85710	31284.15	5967	71604	26135.46	2067.11
Bhatkal	24619	73857	26957.81	6094	73128	26691.72	1931.38
Haliyal	41485	124455	45426.08	20820	249840	91191.60	4918.24
Honnavar	47828	143484	52371.66	8849	106188	38758.62	3280.69
Karwar	11218	33654	12283.71	5460	65520	23914.80	1303.15
Kumta	35891	107673	39300.65	5820	69840	25491.60	2332.52
Mundgod	32122	96366	35173.59	8686	104232	38044.68	2635.86
Siddhapur	43881	351048	128132.52	18897	226764	82768.86	7592.45
Sirsi	52230	417840	152511.60	18845	226140	82541.10	8461.90
Supa	19052	57156	20861.94	8224	98688	36021.12	2047.79
Yellapur	30053	240424	87754.76	11007	132084	48210.66	4894.76
Total	**366949**	**1731667**	**632058.46**	**118669**	**1424028**	**519770.22**	**41465.83**

Figure 11 gives the annual biogas production from livestock residues in Uttara Kannada. It is evident that in majority of the villages in the district, annual biogas energy generated from biogas ranges from 0.1 to 0.5 million kWh. In 340 villages of Mundgod, Haliyal, Karwar and Siddapur taluks biogas energy generation is 0.5 to 1 million kWh. Few villages in Bhatkal, Honnavar and Mundgod taluk have biogas based energy production of 1-12 million kWh per annum.

Figure 12 gives the availability to demand ratio of biogas resource in the district. In more than 50% of the villages (625 villages) the availability is less than demand; which are called biogas energy deficit regions. In 334 villages of Siddapur, Yellapur and Supa taluks supply to demand ratio is between 1 and 2. There are 275 villages in Ankola, Mundgod and eastern Yellapur taluk, availability is more than twice of biogas demand. About 40% of the villages have adequate biogas potential to meet the domestic needs. These villages are to be considered for dissemination of biogas technology in the district.

4.2 Techno-Economic analysis of Bio-energy technologies (BETs)

The major applications of bio-energy in the country are

i. Domestic use i.e. for cooking, space heating (during winter), water heating (for bathing and livestock) and lighting;
ii. In rural industries (or home industries), for agricultural and horticultural crops processing, bricks and tiles manufacturing;
iii. Biogas production; and
iv. Electricity production (community level, at few locations)

Biomass and agro-horticultural residues are the main sources of bio-energy applications in the country followed by biogas, since most of the bio-energy based application requires combustion and heat transfer. Normally the fresh biomass contains about 20-60% of moisture (which cannot be burnt effectively), needs to be dried so that they are suitable for combustion. In Uttara Kannada, solar drying is adopted to remove moisture content in the biomass. However the energy obtained from biomass is depends on the content of the fuel as well as the efficiency of the stoves or combustion method used, analysis of fuel efficient BET would contribute to the improvement of the technologies.

4.2.1 Cook stoves: The most commonly used stoves in the rural households are either made from mud or from stones (or both). These traditional stoves (TCs) are constructed by local people and have efficiency less than 10%. Also, in traditional stoves oxygen supply is not sufficient which may lead to the generation of CO (carbon monoxide). It is estimated that 826 million Indians depend on TCs that burn fuel wood or coal which causes pollution and the maximum temperature obtained is limited to lower values [26]. In order to overcome these barriers, CST (formerly ASTRA of IISc) has designed an Improved Cookstove (ICs) to give maximum heat transfer with improved efficiency (20-35%) which allows the complete combustion of fuel [27]. There are many ICs are available in market which give better efficiency than TCs and give complete combustion of fuel without CO gas emission. National Biomass Cookstoves Initiatives (NBCI) launched by MNRE (Ministry of New and Renewable Energy) on 2nd December 2009, has the primary aim to enhance the use of biomass ICs. MNRE perused the BIS on solid biomass cookstoves – portable that was brought out by BIS in 1991 to examine the applicability of the standard and test protocols in view of the newer designs of cookstoves. This standard has been revised and draft is forwarded to BIS in November 2011 for further action. The ministry has suggested some standard performance factors for the cook stoves which are given in Table 5 [28].

Table 5: Performance parameters for improved cook stoves

Type of biomass cookstove	Standard performance parameters		
	Thermal efficiency (%)	CO (g/MJd)	PM (mg/MJd)
Natural draft type	>25	<= 5	<= 350
Forced draft type	>35	<= 5	<= 150

(Source: MNRE (NBCP), 2013)

Life span of traditional stoves built in rural areas is limited due to the usage of mud and stones. But ICs are constructed with modern technology and science which gives longer lifetime. Due to thermal stress, cracks develop in the walls of a mud stove where as ICs can withstand in higher temperature [29]. However the ICs are recommended due to higher efficiency, durability and less GHG (Green House Gas) emission over traditional stoves (TCs).

4.2.2 Biomass fueled steam generation: Steam is generated through direct combustion of bio mass which is a viable energy carrier in many applications. Bio mass fired power systems produce both heat as well as electrical energy mainly used in CHP (Combined Heat and Power) plants. These systems have found application is many industries such as paper and pulp, sugar, steel and plywood industries. In many applications, steam of high pressure and temperature generated from bio mass combustion is used to run the turbine which is coupled with alternator [30]. Steam of low pressure and temperature is collected from the outlets of turbine and used for other applications such as heating, drying or primary heating of water. Co-firing of biomass in modern large scale coal power plants is efficient and cost effective. Efficiency of co-fired plants is more (35-45%) compare to the biomass dedicated plants. Using low cost bio mass from solid waste, crop residues etc, investment may have shorter payback period of 2-3 years [31].

4.2.3 Biogas Technology: The district has significant livestock population which is main source of dung production. Cattle dung offers a very high potential of biogas production which can meet the ever increasing domestic fuel demand. The slurry generated in the biogas production process is good manure which can be used to prepare compost or directly fed to agricultural or horticultural plantations. Biogas mainly comprises of methane (60-65%) and carbon dioxide (35-40%). Hydrogen sulphide and water vapor accounts a small fraction in biogas mixture. Biogas is about 20% lighter than air which cannot be converted into liquid like LPG (Liquefied Petroleum Gas) under normal temperature and pressure (NTP) [32]. Biogas generation from dung or agro-horticultural residues is dependent on temperature, carbon : nitrogen ratio, pH and retention days. Temperature is the most prominent factor that affects the biogas generation; generation stops below the temperature of 10°C. The optimum conditions for biogas generation are: temperature 30-35°C, pH 6.8-7.5, carbon : nitrogen ratio (C:N) 20-30, solid contents 7-9%, retention time 20-40 days. The retention time decides the rate of digestion, longer the retention time more the gas generated for a given amount of waste. There are many technologies are available for biogas generation depending upon the availability of waste. The most widely used technologies are [33]:

i. Fixed Dome model (40 and 55 days retention period)
    a. Deenabandhu brick masonry
    b. Deenabandhu ferro-cement in-situ construction
ii. Floating Dome model (30,40 and 55 days retention period)
    a. KVIC (Kadhi and Village Industries Commission) floating metal drum

   b. KVIC reinforced cement concrete (RCC) digester

iii. Prefabricated Model for limited field trial (40 days retention period)
   a. Sintex - HDPE prefabricated Deenbandhu

iv. Optimized design developed by Application of Science and Technology to Rural Areas (ASTRA) of IISc [34].

v. Fixed dome type designed by University of Agricultural Sciences - Bhagyalaxmi design.

vi. Raitabandu Biogas Plant - designed by a farmer from Sagar Taluk, Shimoga district to suit the needs of the Malnad region.

4.2.4 Applications of Biogas: Biogas is mainly used for cooking as it can be directly burned which is more efficient and produces negligible fumes. Biogas can substitute fuel wood for cooking and water heating. Biogas produced in the district can meet 50% of the total gas demand (Table 3). The other applications of biogas are for lighting and electricity generation. Biogas has better illumination ability; it can be used for lighting instead of kerosene lamps.

Electrical energy generation is an important application of biogas where it is used to produce steam or used with diesel in co-generation units. Biogas has higher calorific value (4700 kcal) which can be effectively utilized for electricity generation. Biogas is used with conventional fuels such as diesel or coal in CHP (Combined Heat and Power) generation which improves the efficiency of the plant. The system capacity ranges from 3 to 250 kW which is a decentralized system. This can meet the rural domestic electricity demand and enables hybridization with other renewable energy based generating systems on micro/smart grid platform. A community level plant which is fueled by biogas and diesel can supply the irrigation pump sets during day time and lighting load during night. In the same manner if it is hybridized with solar, wind or pico hydro plants (depending on the potential), then a micro grid can meet the energy demand in decentralised manner. The standalone generating mechanism leads to sustainable development by ensuring the reliable and pollution free power generation. Upgradation to smart grid infrastructure is possible through integration of communication and automatic control networks.

MNRE has initiated “Biogas based Distributed/Grid Power Generation Programme” (4th January 2006) to promote biogas based power generation especially in rural areas in a decentralized way. It also helps in utilizing the waste generated in that region and produces valuable manure as a byproduct. There are about 98 installed plants with cumulative capacity of 793.25 kW in the country (as of March 2011). There are 250 plants that are under installation adding 5824 kW in future. Karnataka has 5 installed plants with total capacity of 66 kW and 36 plants are being installed (695 kW). The ministry is also providing the financial aid for biogas based power generation plants depending upon the ratings, maximum up to 40% of the plant cost [35]. Cost of the biogas plant depends upon the size gas storage area and retention duration. For a fixed dome Deenabandhu model with retention period of 40 days, cost ranges from INR 12,000 to INR 24,000 (depending on the size of 1 m^3 to 4 m^3). Similarly if retention period is 55 days then cost ranges from INR 16,000 to 31,000. For a KVIC masonry digester and steel gas holder which has retention period of 30 days, plant cost varies from INR 19,000 to 28,000 (1 m^3 to 4 m^3). If retention period is increased to 40 days the cost also increases, i.e. INR 24,000 for 1 m^3 and INR 39,000 for 4 m^3 plant. The average payback period of biogas plant decreases with increase in size of the plant which ranges from 4.07 years (1 m^3) to 2.45 years (4 m^3) [33]. The cost of electrical energy produced from biogas is about INR 5.5 per kWh and the capital cost ranges from INR 1,50,000 to 2,00,000 depending upon the capacity of the plant (CHP plant). In case of direct combustion of fuel wood, operating cost is about INR 2.5 per kWh and capital cost varies from INR 60,000 to 1,00,000 [36].

4.2.5 Biomass gasification: Fuel wood can be converted into gas using thermo-chemical processes with only 2-4% of ash. Gasification is carried out in oxygen starved environment so as to generate Carbon monoxide and Hydrogen which are combustible. The reactions are carried out in elevated temperature of 500-1400 °C and pressure of 33 bar (480 psi). The main difference between biomass gasification and biogas generation is that, wet organic feed stocks such as animal dung and sewage waste are used in biogas production. Mostly fuel wood, forest residues, agricultural and horticultural residues are the main sources for gasification. Air based gasifiers normally produce a gas with high nitrogen content, whose calorific value varies between 4 and 6 MJ/Nm^3 (100-1200 $kilocalories/Nm^3$). Oxygen and steam based gasifiers produce a gas with relatively high calorific value of 10 to 20 MJ/Nm^3. Gas generated from bio mass is also called as Producer gas which is highly combustible [37].

Pyrolysis is the primary step of converting biomass into gas in which the biomass decomposition takes place, producing volatile materials (75-90%) in the form of gas and liquid, and char which is non-volatile. In the later steps (gasification), volatile hydrocarbons and char are converted to combustible gas. Figure 13 shows the biomass gasification process and byproducts generated in the process.

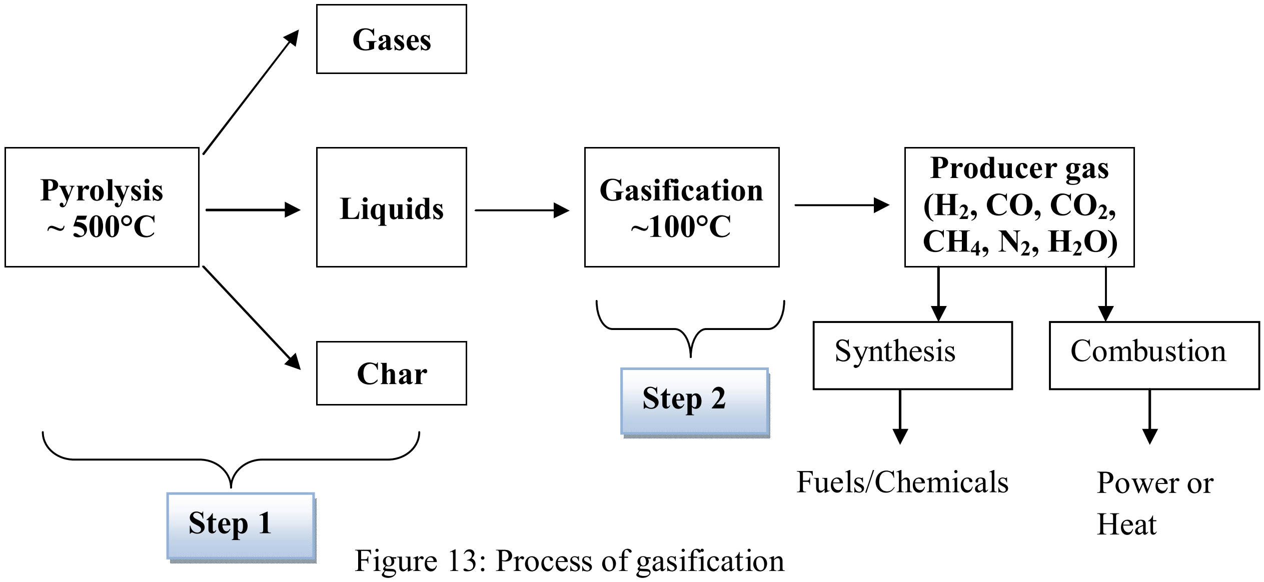

Figure 13: Process of gasification

Many types of biomass gasifiers [Table 5] have been developed depending upon the flow of fuel and oxidants and means of supporting structures [38]:

Table 5: Types of gasifier

Gasifies type	**Flow direction**		**Type of support**
	Fuel	**Oxidant**	
Updraft fixed bed	Down	Up	Grate
Downdraft fixed bed	Down	Down	Grate
Bubbling fluidized bed	Up	Up	None
Circulating fluidized bed	Up	Up	None

(Source: NREL)

4.2.6 Electricity generation from biomass gasification: End product in gasification process is combustible gas which may either be used for cooking or in steam power plants. Gas is burnt and steam high pressure steam is obtained at very high temperature. Steam is used to run turbines which are mechanically coupled with alternators. Alternators generate electrical power depending on the capacity which may be fed to consumers or supplied to grid. The combustible gas may be directly fed to external combustion engines which are connected to alternators. However the output of the alternator is same but the efficiency in latter method is marginally higher. Normally the producer gas is used in dual fueled generating stations in order to reduce the stress on fossil fuel demand.

The capacity of the biomass based electricity generation ranges from few kilowatts to hundreds of kilowatt. Fuel requirement for gasifier is around 1.2 kg in order to generate 1 kWh of electricity which works for 4 to 5 hours/day. These type of systems are best suited for distributed generation, have the capacity to meet the demand of domestic electricity consumption. Remote area electrification in absence of conventional grid supply has been successfully implemented [39]. Producer gas can be used with conventional fuels such as diesel or natural gas which allows 60-80% savings in fossil fuel consumption. MNRE is encouraging gasifier projects for both in community level and for individual household. Central Financial Assistance (CFA) will be given for various components of gasifier plants from 15,000 per kW to 5 lakhs (one time) depending upon the application and benefitting population. Also the ministry organizes technical courses for technicians in order to understand the technology and for effective implementation [40]. At present, few number of biomass gasifier plants are working in the country accounting cumulative capacity of less than 125 MW. Though the operating cost of the plant is marginally higher than the present grid electricity cost, due to lack of public interest and limited shared knowledge of technology, bio energy technologies are sparsely used.

4.3 Energy Plantation

Basically, energy plantation refers to the plantation or forest which is exclusively cultivated for fuel wood extraction. The species selected for plantation should grow in shorter period of time and give maximum biomass and litter. The fuel wood harvested from energy plantations should have higher calorific value and produce less ash. *Casuarina* is one such species suitable along coast has the heat value of $280.6*10^6$ kcals/year/ha (about 3,83,364.6 ha of area needed to install 1,000 MW thermal power plant with energy plantation). By selecting suitable native species for plantation valuable byproducts can be harvested such as fruits, oil (oil seeds), feedstock for cattle, organic compounds, fibre, leaves for manure and other forest products. Data collected from Forest Department reveals that annual woody biomass available is in the range 11.9 to 21 t/ha/yr. An energy forest raised at Hosalli village in Tumkur district to support a wood gasifier plant has annual yield of 6 t/ha/year [41]. The energy plantation is an everlasting energy source (with periodic maintenance) which are independent and decentralized. The prominent uses of these plantations are

a) Energy obtained is similar to Indian coal
b) Wood contains less sulphur and does not pollute while burning with sufficient oxygen
c) Ash after burning wood can be used as good fertilizer
d) Plantations reduce soil erosion by water and wind, also absorbs GHG which slows down global warming
e) Since plantation and the power plants associated with it require constant attention and periodic maintenance, it will produce employment. On an average, 1 ha f energy plantation could give employment for 7 people.

4.4 Scope for energy plantations in Uttara Kannada

District has about 22,800 ha of barren land which can be used for energy plantation. These energy forests have the potential to yield 1,36,800 t/yr of biomass. If 80% of these biomass are used for power generation using gasifies, 91.2 GWh of electric energy can be generated. The electricity generated will be in a decentralized manner which is more reliable and has lesser T&D losses. This system can be further hybridized and grid connected with smart grid platform. The gasifier expansion in rural area with energy plantation would reduce the fossil fuel dependency. This approach has prominent advantages such as energy independence, barren land utilization, employment generation in rural area, switching over from fossil fuel consumption, implementation of next generation RETs (Renewable Energy Technologies), etc.

4.5 Economic analysis

Bio energy is in-exhaustive source, freely available in most of the situations (or very inexpensive). BETs mainly use the residues (byproducts) of forest, agriculture, horticulture etc and animal waste which are abundantly available in rural areas. Municipal Solid Waste (MSW) is the source for bioenergy (biogas) in urban area with massive supply. Hence the availability of resource for bioenergy generation is plenty and has negligible cost compare to fossil fuels. Table 6 shows the comparison of different power plants under capital cost requirements. Biomass based power generation system requires less capital cost compare to other technologies since land, infrastructure and technology requirements are less expensive. Table 7 gives the comparison of overnight capital cost and O&M costs of different power plants. The generation cost of electricity from bio energy is marginally high compare to conventional method. Nevertheless cost/kWh is less in case of direct biomass combustion since fuel wood is freely available. Table 8 gives the cost/MWh energy generation from different technologies.

Table 6: Capital cost comparison of power plants

Type of technology	Capital cost (million rupees/MW)
Solar photovoltaic	300-400
Micro-hydel	40-60
Wind	40-50
Biomass	20-40

(Source: Biomass gasifier-based power generation system back to basics, with a difference, The Energy and Resource Institute. <http://www.teriin.org/index.php?option=com_content&task=view&id=59 >)

Table 7: comparison of overnight capital cost and O&M costs

Power plant	Overnight Capital Cost ($/kW)
Coal	2844-5348
Natural gas	665-2060
Nuclear	5339
Fuel cell	6835
Geothermal	4141
Hydropower	3078
Wind	2438
Wind offshore	5975
Solar thermal	4692
Solar PV	4755
Biomass	3860
MSW-Landfill gas	8232

(Source: EIA, <http://www.eia.gov/oiaf/beck_plantcosts/>)

Table 8: Electrical energy generation cost comparison of different power plants

Type of Power Plant	Rs/MWh (at 5% Discount rate)	Rs/MWh (at 10% Discount rate)
Nuclear	2440.8	4217.24
Coal	3400.2	4643.17
Gas	3877.65	4339.85
Hydro – Small hydro	4743	8501.27
Large hydro	4557.15	8841.65
Wind – Onshore	4887	8346.17
Offshore	6276.15	8999.03
Geothermal	4438.35	7244.28
Solar – PV	12600.45	19058.99

PV (rooftop)[1]	15854	23273.48
Solar thermal[2]	9503.1	14809.73
Biomass[3]	Rs. 4.55 to 6.75	

(Source: International Energy Agency (IEA) Nuclear Energy Agency (NEA), Organization for Economic Co-operation and Development, 2010, MNRE, Case Studies of Selected Biomass Power Projects in India)

[1] Solar PV (rooftop) system in Germany,

[2] Solar thermal systems in United States

[3] MNRE, Case Studies of Selected Biomass Power Projects in India

5. CONCLUSION

In Uttara Kannada district, bio energy meets the household energy demand. The supply/demand ratio of bioresources in the district ranges from less than 0.5 (Bioresource deficit) to more the 2. The coastal and the extreme eastern part of the district (coastal villages of Karwar, Ankola, Kumta, Honnavar and Bhatkal with eastern part of Mundgod and Haliyal) are the fuel wood deficit places. The bioresource supply is dwindling in the district evident from the reduced bioresource supply to demand ratio from 8-9 [15] to 2. This necessitates sustainable management approaches with augmentation of forest resources.

In coastal regions (Kumta, Honnavar, Ankola, Bhatkal, Karwar), availability of agro-horticultural residues is more than the current demand which has the potential to meet the rural household energy demand. Similarly in Sirsi, Siddapur and Yellapur taluks, forest biomass potential could meet the energy demand. In Mundagod, Haliyal and in coastal villages, availability of animal residues provides the scope for biogas production. About 40% of the villages have adequate biogas potential to meet the domestic needs. These villages are to be considered for dissemination of biogas technology in the district. Biogas can also be used for electricity generation and the byproduct, i.e. slurry is used for organic manure production which is a very good fertilizer. Advanced BETs will encourage the bio energy use and make the application simpler. Improved cook stoves, biomass gasification and other new bioenergy technologies are yet to available in rural areas which could change the older energy conversion pattern with higher efficiency. BETs are economically feasible and environmental friendly apart from ensuring sustenance of resources.

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Opportunities for Decentralized Wind Applications in Uttara Kannada

SUMMARY

Wind is one of the promising renewable sources which can substitute fast depleting fossil fuels sources. Windmills have been used for centuries to grind grain and pump water in rural areas. It has the advantage of being harnessed on a local basis for applications in rural areas and remote areas. Water pumping for agriculture and plantations is probably the most important application that contributes to the rural development through multiple cropping. Wind resource assessment is the primary step towards understanding the local wind dynamics of a region. Climatic average datasets of meteorological variables containing wind speed data for the period of 1961~1990 compiled from different sources I were used for the potential assessment of wind speed in the district. These were validated with the dataof meteorological observatories at Karwar, HonnavarandShirali obtained from the Indian Meteorological Department, Government of India, Pune. Analysis showed the seasonal variation of wind speed in the region. Wind speed varies from 1.9 m/s (6.84 km/hr.) to 3.93 m/s (14.15 km/hr.) throughout the year with minimum in October and maximum in June and July. District experiences annual average wind of 2.5 m/s to 3.0 m/s in all taluksindicating the prospects for WECS installation. Hybridizing wind energy systems with other locally available resources (solar, bioenergy) would assure the reliable energy supply to meet the energy demand at decentralized levels.

Keyword: Windmill, Mean wind speed, Decentralized generation, Hybridization of resources

1. INTRODUCTION

Energy extraction from wind is one of the oldest energy harvesting technologies that is being used for centuries. Winds are caused by the rotation of the earth and the heating of the atmosphere by the sun. The total annual kinetic energy of air movement in the atmosphere is estimated to be about 3 x 105 kWh or about 0.2% of the solar energy reaching the earth. The maximum technically usable potential is estimated to be theoretically 30 trillion kWh per year, or about 35% of current world total energy consumption [1]. The power in the wind blowing at 25.6 km/h is about 200 W/m^2 of the area swept by the windmill. Approximately 35% of this power can be captured by the windmill and converted to electricity. The kinetic energy of the air can be transformed to mechanical and then to electrical form of energy using fans, gears, turbine and generator system. Windmills are the modern world electricity harvesting technologies which accounts for more than 2 GW installed capacity worldwide [2]. Electricity generation from wind is directly proportional to the air density, swept area of blades and cube of the wind velocity. Since the wind velocity is more tentative, hence optimizing the blade area, maximum energy can be extracted for particular wind speed at given place [3].

$$P = \left(\frac{1}{2}\right) * \rho * A * V^3 \qquad (1)$$

where, P –Wind power ρ – Air mass density

A – Swept area (area of wind flow) V – Wind velocity

The annual wind speed at a location is useful as an initial indicator of the value of the wind resource. The relationships between the annual mean wind speed and the potential value of thewind energy resource are listed below;

Annual Mean wind speed @ 10m Ht. (m/s)	Indicated value of wind resource
<4.5	Poor
4.5-5.4	Marginal
5.44 - 5.7	Good to Very Good
> 6.7	Exceptional

Uttara Kannada district located in the west coast and inWestern Ghats region of Karnataka state is blessed with good wind potential. Harnessing of wind energy could play a prominent role in meeting the energy demand in the region since electricity supply is unreliable in most of the times. Wind energy potential in the district could meet the regional electricity demand through wind energy conversion system (WECS) avoiding plenteous greenhouse gas (GHG) emission and fossil fuel. It can be harnessed locally in a decentralized manner for applications in rural areas and remote areas such as water pumping for agriculture and plantations. Wind driven electric generators could be utilized as an independent power source and for purposes of augmenting the electricity supply from grids. In coastal densely populated taluks like Karwar, Kumtaand Bhatkal in Uttara Kannada District, decentralized production of electricity would help local industries, especially seasonal agro processing industries like cashew, etc. WECS can be hybridized with solar, biomass and any other available local energy resource to provide cent percent reliable power since wind flow is maximum during monsoon when solar insolation and dry biomass availability is lesser [4].

Wind resource assessment: Wind resource assessment is the primary step towards understanding the local wind dynamics of a region. Wind flow developed due to the differential heating of earth is modified by its rotation and further influenced by local topography. This results in annual (year to year), seasonal, synoptic (passing weather), diurnal (day and night) and turbulent (second to second) changes in wind pattern [5]. Increased heat energy generated due to industries and escalating population in urban areas result in heat islands which affects the wind flow as well.

2. OBJECTIVE

Objective of the present study is to assess the taluk wise annual wind potential in Uttara Kannada district and assess techno-economic feasibility of wind energy harvesting options, to meet the regional electricity demand.

3. STUDY AREA, DATA AND METHODS

Uttara Kannada is a 4th biggest district of Karnataka state, located between 13° 55′ and 15° 31′N and 74° 9′ and 75° 10′ E. Total population of the district is 14,36,847, and more than 70% of the people live in rural area or in semi urban area. District is located in the Western Ghats ranges sheltering abundant flora and fauna. More than 75% of the total area is forest covered and has 140 km costal belt [6].Figure 1 illustrates the topographic undulations of the region. Topographically, the district lies in three distinct zones namely narrow and flat coastal zone, abruptly rising ridge zone and elevated flatter eastern zone. The coastal zone is thickly populated with coconut clad villages. Ridge zone is a part of the main range of Western Ghats, which runs north to south, parallel to the coast. The flat eastern zone joins the Deccan plateau. The taluks, which comprises the narrow flat coastal zone, are: Karwar, Ankola, Kumta, Honnavar and Bhatkal. Similarly, taluks, which comprises the ridge zone, are: Supa, Haliyal, Yellapur, western Sirsi, and western Siddapur. Flatter eastern zone includes Mundgod, eastern Sirsi and eastern Siddapur. Four agro-climatic zones based on geography and climate are coastal, evergreen, dry deciduous and moist deciduous. There are 1291 villages, 7 towns, 5 city municipal corporations/town municipal corporations/outward growth/census towns and 2 reservoirs in the district [http://uttarakannada.nic.in/].

Data and Method

Synthesised wind data: Synthesised wind data available from various sources provide preliminary understanding of the wind regime of a region. Depending on the physiographical features and climatic conditions, these data help assess wind potential in the region of interest validated by long term surface wind measurements.

There many wind speed data sets are available of different time periods such as National Aeronautical and Space Agency (NASA) Surface Meteorology and Solar Energy (SSE), National Oceanic and Atmospheric Administration (NOAA-CIRES), Climate Research Unit (CRU) etc. However previous studies are evidently showed that CRU data are reliable and are closer to the Indian Meteorological Department (IMD) surface data and hence used in the present study [7].CRU at the University of East Anglia maintains climatic average datasets of meteorological variables whichcontains wind speed data for the period of 1961~1990 compiled from different sources. Further, inter and intra variable consistencychecks are performed to minimize data consolidation errors. The Global Land One-km Base Elevation Project (GLOBE) data of the National Geophysical Data Center (NGDC) were re-sampled to 10’×10’ (ten minute spatial resolution) elevation grids where every cell with more than 25% land surface (those below 25% being considered water bodies) represents the average elevation of 100~400 GLOBE elevation points. The climatic average of wind speeds measured at 2 to 20 m anemometer heights (assumed to be standardized during collection) collated from 3950 global meteorological stations together with the information on latitude, longitude and elevation were interpolated based on a geo-statistical technique called thin plate smoothing splines. Elevation as a co-predictor considers topographic influence on the wind speed and proximity of a region to the measuring station improves the reliability of the interpolated data. During interpolation inconsistent data were removed appropriately. This technique was identified to be steadfast in situations of data sparseness or irregularity [8]. The 10’×10’ spatial resolution wind speed data as climatic averages were available for all global regions (excluding Antarctica) [9].

Data from IMD stations located in the district are also acquired for respective locations and which gave the satisfactory results comparingwith CRU data set. There are 4 IMD stations in the districts which are listed in Table 1. Cup counter anemometers with hemispherical cups measuring 7.62 cm in diameter were used in Indian Meteorological Department (IMD) observatories until 1973. During 1973-1979 these anemometers are replaced with 3 cup anemometers with 127 mm diameter conical cups, which are placed at l0 m above ground, over open terrain in conformity with international practice.

Table 1: IMD stations in Uttara Kannada

Location	Latitude	Longitude	Elevation (m)
Karwar	14° 47'	74° 08'	4
Kumta	14° 26'	74° 25'	8
Honnavar	14° 17'	74° 27'	26
Shirali	14° 05'	74° 32 '	45
Sirsi*	14° 62'	74°85'	610

Data from the meteorological observatories at Karwar(for the period 1952-1989), Honnavar (for the period 1939-1989) and Shirali (for the period 1974-1989) obtained from the Indian Meteorological Department, Government of India, Pune, and daily wind data for the period 1990-1993 for these observatories, from the Indian Meteorology Department, Bangalore. The primary data obtained by installing a cup counter anemometer with mechanical counter fixed on 5 m tall guyed masts at Sirsi and Kumta. The anemometer readings were noted down every three hours during the day and mean wind speeds were obtained.

Anemometers at different meteorological stations are set at different height levels. The wind speed recorded at each station has to be adjusted to any constant height prior to analysis. The standard height according to the World Meteorological Organization is 10 m above the ground level which is used for the analysis [10]. The horizontal component of the wind velocity varies a great deal with height under the influence of frictional and impact forces on the ground. The most common model for the variation of horizontal velocity with height is given by the logarithmic wind profile equation 2[11]

$$(V1/V2) = (HI/H2)^{\alpha} \qquad (2)$$

Where V1 is a wind speed at height H1 of 10m above ground level, V2 is a wind speed at height H2 above ground level, and α is the roughness factor which is determined by substituting the wind speed data obtained with anemometer height in various wind directions, and found to be 0.30. Table 2 gives the month wise average wind speed in the respective locations.

Table 2: Monthly variation in mean wind speed (km/hr) [3]

Month	Karwar	Kumta	Honnavar	Shirali	Sirsi
January	5.96	5.95	5.95	6.78	6.92
February	6.55	7.76	6.00	6.87	6.88
March	8.15	9.09	6.10	7.03	7.20
April	9.65	9.42	6.20	7.25	8.38
May	11.82	9.87	7.21	7.84	9.09
June	12.01	11.83	7.50	8.30	11.19
July	15.27	13.03	7.72	8.50	18.17
August	11.98	11.54	6.66	7.64	14.19
September	7.44	6.71	4.87	5.56	11.14
October	5.41	6.59	4.55	5.42	8.39
November	4.75	6.29	5.04	6.76	7.72
December	5.04	7.73	6.00	9.51	8.42

Figure 2 shows the comparison of mean wind speed in five IMD stations. At higher elevations in the district mean wind speed is comparatively higher and also in coastal region. Wind speed recorded at Honnavar and Shirali stations are lower which are placed at an elevation of 26 m and 45 m respectively.

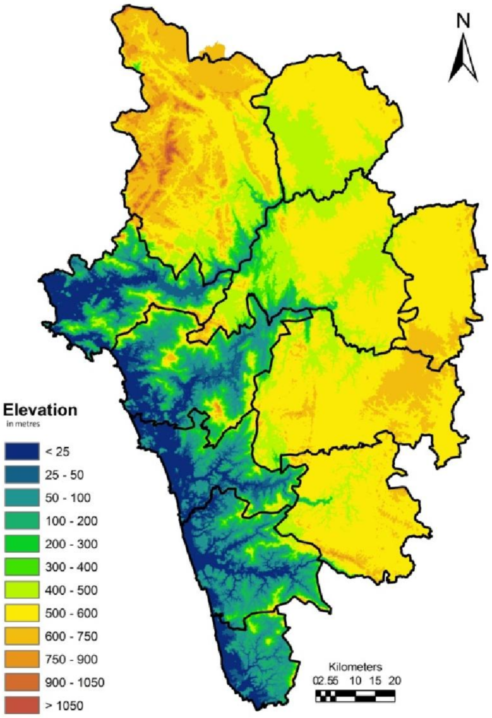

Figure 1: Digital Elevation Model of Uttara Kannada, Karnataka

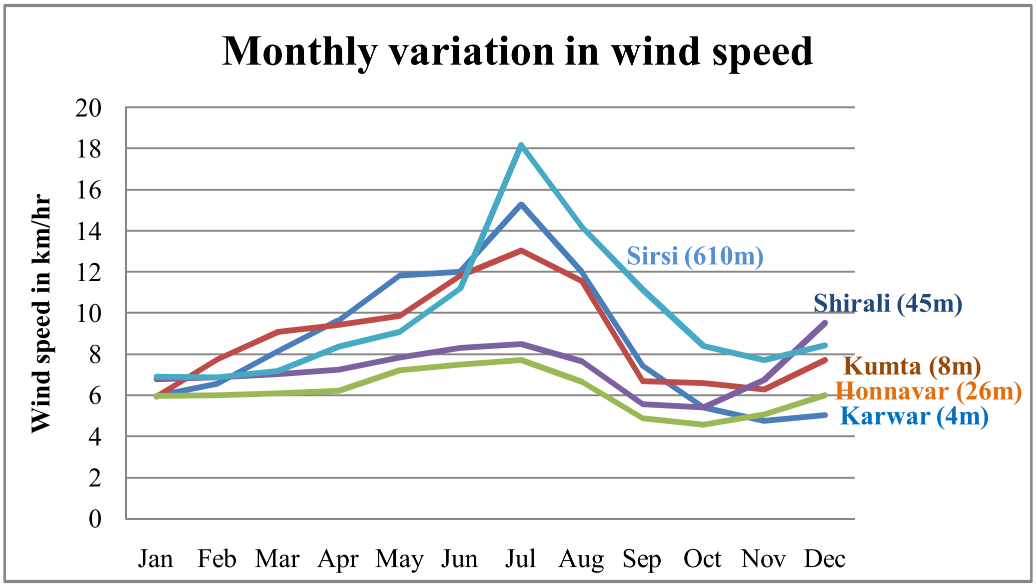

Figure 2: Monthly variation in wind speed

4. RESULTS AND DISCUSSION

Wind profile of Uttara Kannada: Wind speed is seasonal dependent which is normally at its maximum during monsoon season. Wind speed varies from 1.9 m/s (6.84 km/hr.) to 3.93 m/s (14.15 km/hr.) throughout the year resulting minimum in October and maximum in June and July. Annual average wind sped in the district ranges from 2.54 ± 0.04 m/s (9.144±0.144 km/hr.) in Haliyaltaluk to 2.70 ± 0.05 m/s (9.72±0.18 km/hr.) in Karwartaluk. Figure 3 gives the taluk wise annual average wind speed of the district. Ample amount of electrical energy can be generated using blowing wind through wind farms which could meet the major fraction of the current electricity demand of the district through decentralized generation.

Seasonal variation of wind speed: Speed of the wind is quite uncertain and dependent on ambient temperature and pressure, vegetation cover, elevation, topography of the site etc. Uttara Kannada has a mixed topography includes coastal belt, low and high elevation area with forest cover and also planes. From February to May district experiences summer with higher temperature in costal (Karwar, Honnavar, Kumta, Bhatkal and Ankola) and in planes (Mundgod and Haliyal) and comparatively lower temperature in taluks of higher altitudes (Sirsi, Siddapur, Yellapur and Supa). Figure 4 to 6 gives the mean wind speed variability in the district during summer, winter and monsoon months.

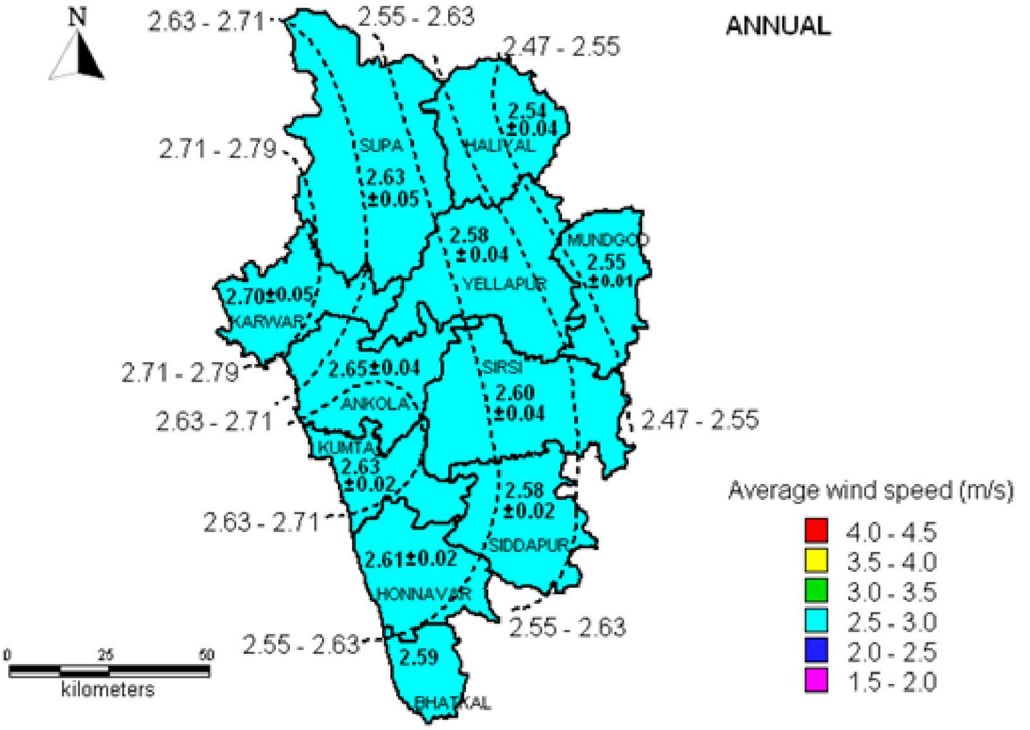

Figure 3: Average annual wind speed of Uttara Kannada

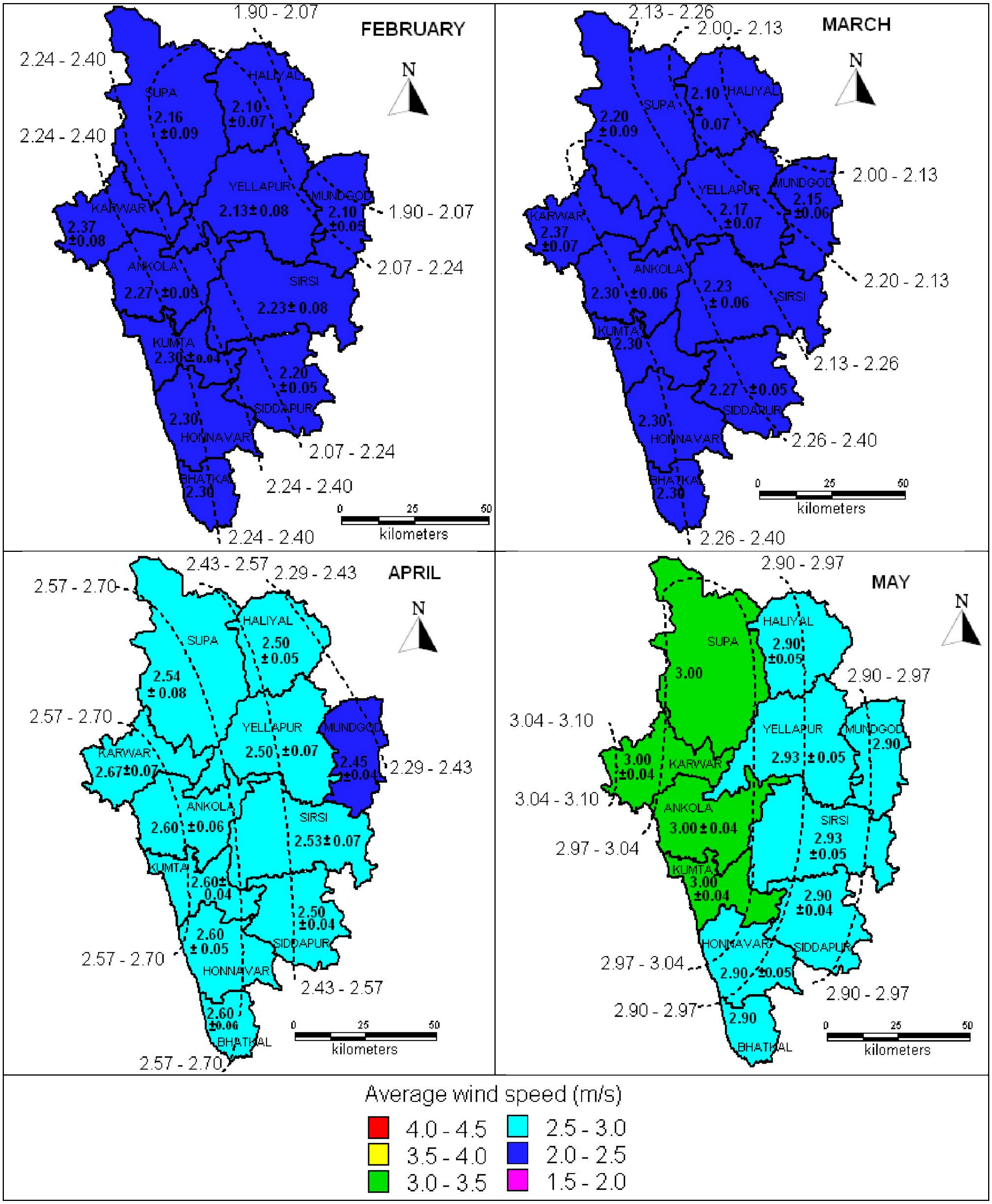

Figure 4: Wind speed variation during summer (m/s)

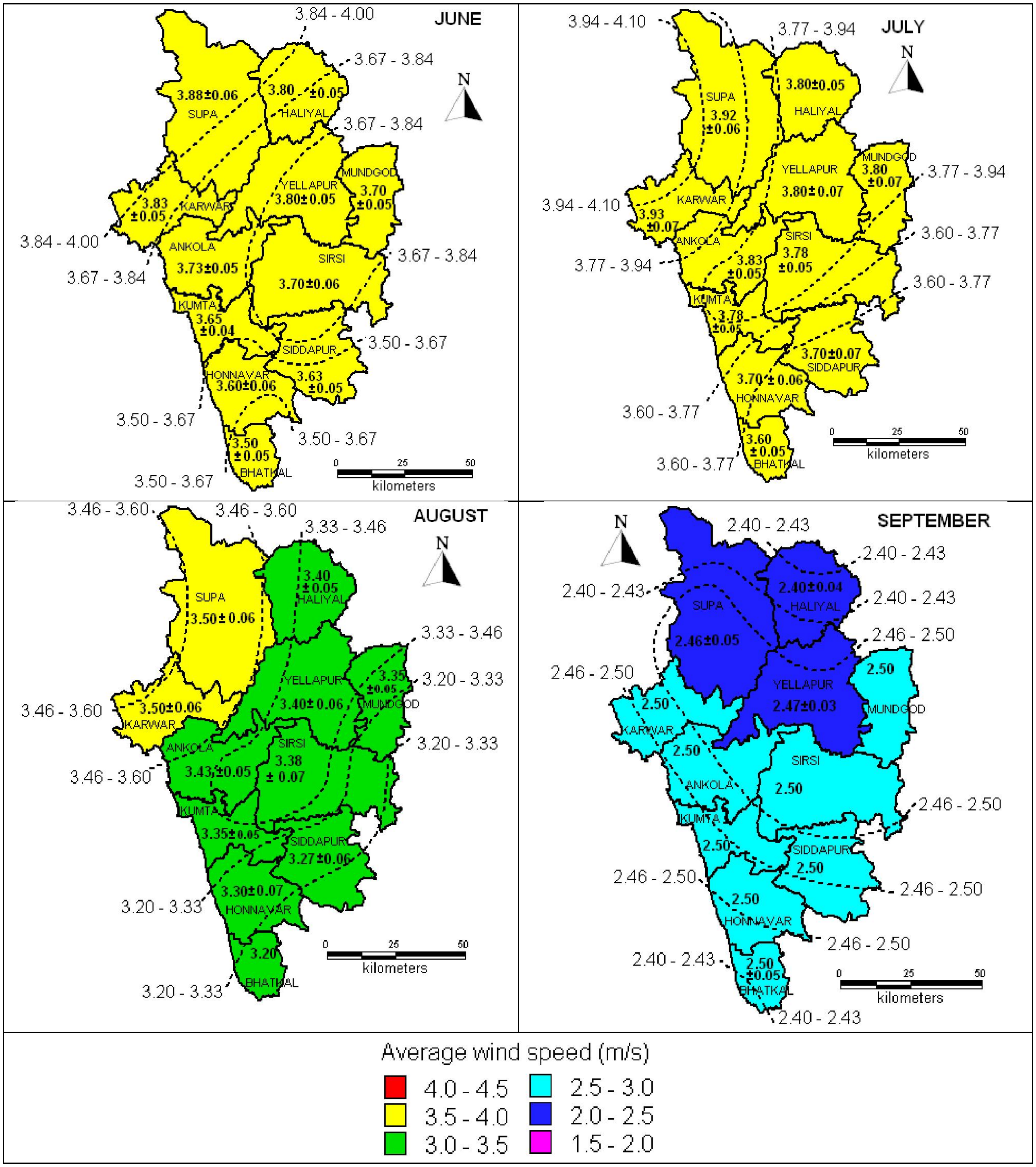

Figure 5: Wind speed variation during monsoon (m/s)

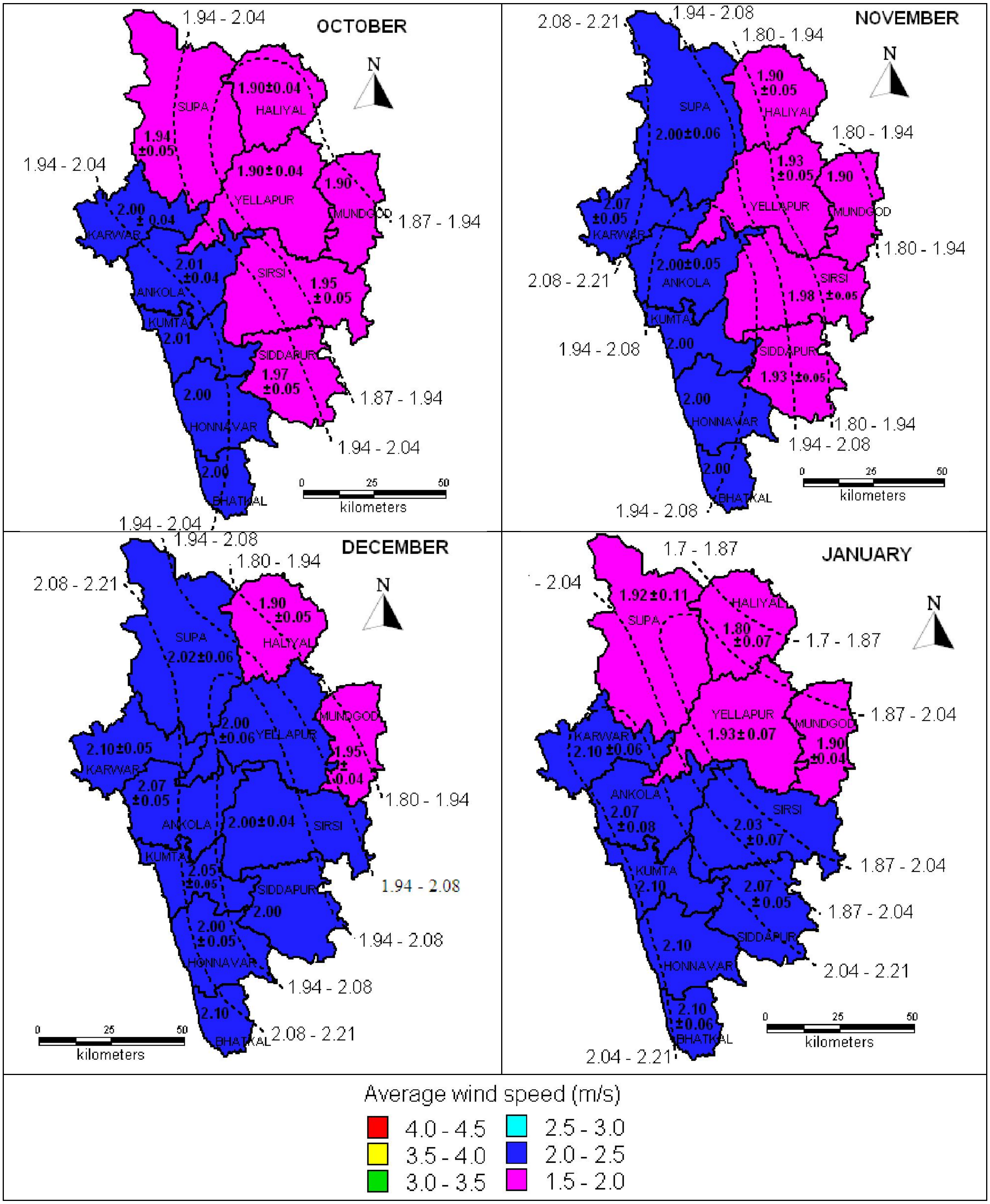

Figure 6: Wind speed variation during winter (m/s)

Wind Energy Conversion System (WECS): Wind Energy Conversion System (WECS) is used to extract energy from wind which in turn converted to mechanical and then electrical energy. Main components of WECS are blades, gears, turbine, generator and pillar to mount all the equipment at the required height. Wind potential assessment is a prominent pre installation procedure to assure perfect selection of site and to harness maximum energy. In order to explore the potential of wind technologies at an increased hub height, hourly surface wind speed measurements at IMD stations were estimated and represented in Figure 5. In almost all the taluk more than 45% of the wind speed is above 2.5 m/s except Honnavar (39.58%). Over 20% of the measured hours crossed 3.5 m/s wind speeds in Karwar, Kumta and Supa, in which Karwar being highest (27.38%). These findings along with relatively higher wind speeds (>2 m/s in high elevation zone) observed in seasonal wind profiles (based on CRU data) are indicative of the prospects of small and medium scale wind applications in Uttara Kannada which are technically achievable and economically viable [12]. Some of these are listed in Table 3.Wind pump for drawing water is an attractive small-scale wind technology for rural energy needs.The agriculture and horticulture intensive zones of Uttara Kannada could get benefited by wind pumps that function at low wind speeds.TheVertical Axis Wind Turbine (VAWT) that can function in wind speeds as low as 1 m/s could be more effective during low wind speed seasons in the region [13].Reduction in wind speeds and duration could be compensated by hybridizing wind with available alternative resources. Assessment of solar energy potential substantiates that it receives monthly average global insolation (incoming solar radiation) > 5 kWh/m^2/day [7]. Hence wind–solar hybrid systems could be considered for endured energy supply in the region. Small-scale wind turbines could also be used in conjunction with biomass gasifies /diesel generators especially in remote areas, although diesel is not a clean option [14]. Battery charging based on wind systems supplements the energy requirements during reduced wind speeds.

Rated power, P_{rated} (kW)	**Rotor swept area (m^2)**	**Sub-category**
$P_{rated} < 1$ kW	$A < 4.9$ m^2	Pico wind
1 kW $< P_{rated} <$ 7 kW	$A < 40$ m^2	Micro wind
7 kW $< P_{rated} <$ 50 kW	$A < 200$ m^2	Mini wind
50 kW $< P_{rated} <$ 100 kW	$A < 300$ m^2	(Not defined)

Table 3: Available small-scale wind turbines [12]

Techno-economic Feasibility: Power harnessed by the WECS can be expressed using expression as given below;

$$Pavail = \left(\frac{1}{2}\right) * \rho * A * V^3 * Cp \qquad (3)$$

Where, P – Wind power ρ – Air mass density
A – Swept area (area of wind flow) V – Wind velocity
and Cp – Beltz constant (maximum = 59.3%) taken as 0.4

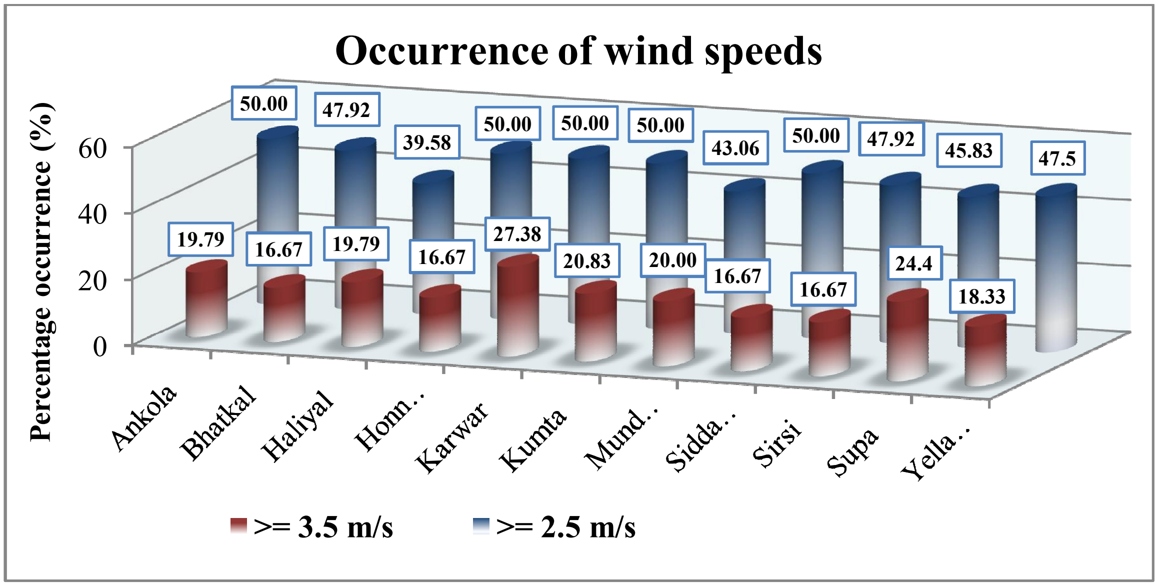

Figure 5: Percentage occurrence of wind speeds

Wind potential available in the district is estimated using equation 3 and given in Table 4.

Table 4: Wind power potential estimation

Month	**Wind speed m/s**		**Power harnessed at A= 30 m^2 (kW)**		**Power harnessed at A= 160 m^2 (kW)**	
	Min	Max	Min	Max	Min	Max
January	1.80	2.10	42.69	67.79	228.61	363.03
February	2.10	2.37	67.79	97.44	363.03	521.83
March	2.10	2.37	67.79	97.44	363.03	521.83
April	2.45	2.67	107.65	139.33	576.48	746.14
May	2.90	3.00	178.53	197.64	956.05	1058.40
June	3.50	3.88	313.85	427.57	1680.70	2289.71
July	3.60	3.93	341.52	444.31	1828.92	2379.38
August	3.20	3.50	239.86	313.85	1284.51	1680.70
September	2.40	2.50	101.19	114.38	541.90	612.50
October	1.90	2.01	50.21	59.44	268.87	318.33
November	1.90	2.07	50.21	64.93	268.87	347.69
December	1.90	2.10	50.21	67.79	268.87	363.03
Total			**1611.49**	**2091.91**	**8629.85**	**11202.58**

Estimation shows that Micro and Mini WEC systems are feasible for the district since minimum and maximum power can be harnessed ranges from 1611.49 kW to 2091.91 kW for the swept area of 30 m^2 (micro model) and from 8629.82 kW to 11202.58 kW for swept area of 160 m^2 (mini model).

Cost of the wind turbines depend on the size, since the transportation and installation difficulties increase with the size. Cost per kilowatt of typical wind turbine ranges from USD 1050 to 1350 in India [15]. As the capacity increases cost/kW decreases but the size of the turbine and blade length increases.Table 5 gives the cost estimation of WEC system.

Table 5: Cost estimation of WECS

Particulars	**Capacity of the turbine**	
	1.5 kW	10 kW
Manufacturing cost	1950	13000
Battery bank	237	1422
Civil work and installation	105	702
Inverter	79	527
Maintenance charge & others	263	1756
Total cost	2634	17407
Annual energy generated (kWh)	3500	30000
Unit cost of electricity (USD/kWh)	0.75	0.58

A typical 1 kW turbine can generate electrical energy of 1000- 3000 kWh per annum depending on the power density of wind [16]. About 70% of the total system cost is only for wind turbine followed by 9% for battery, 4% for civil work [17, 18]. Unit cost of electricity generated from WECS varies from USD 0.5 per kWh to USD 0.75 per kWh. However with the technology improvement and optimizing the system lower generation cost can be achieved.

5. CONCLUSION

Wind is one of the promising renewable sources which can substitute fast depleting fossil fuels sources. Wind energy potential in the district could meet the electrical energy consumption in domestic through decentralized generation and wind turbine driven pumps can decrease the dependency on grid supply for irrigation. District experiences annual average wind of 2.5 m/s to 3.0 m/s in all the taluks which opens wide range prospects for WECS installation. Hybridizing wind energy systems with other locally available resources would assure the reliable energy supply for domestic and irrigation demand. Small and medium scale WEC systems are feasible for the community level installation which leads to abundant amount of carbon dioxide emission reduction.

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Hydroelectric resource assessment in Uttara Kannada District, Karnataka State, India

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Abstract

The amount of power available at a given site is decided by the volumetric flow of water and the hydraulic head or water pressure. In hydro schemes, the turbines that drive the electricity generators are directly powered either from a reservoir or the ‘run of the river’. The large schemes may include a water storage reservoir providing daily or seasonal storage to match the production with demand for electricity. These schemes have been producing power in Karnataka for many years, with the first hydroelectric station built in 1942. The majority of them are in Uttara Kannada district. Due to environmental constraints, further construction of storage reservoirs is limited and attention has been focussed towards developing environmental friendly small-scale hydro schemes to cater for the needs of the region. In this paper, the assessment of potential carried out in the streams of Bedthi and Aghnashini river basins in Uttara Kannada district of Western Ghats is discussed. Potentials at five 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 years of precipitation data and the subsequent power and energy values computed are in conformity with the power calculations based on stream gauging. It is estimated that, if all streams are harnessed for energy, electricity generated would be in the order of 720 and 510 million units in Bedthi and Aghnashini basins, respectively. This exercise provides insight to meeting the regional energy requirement through integrated approaches, like harnessing hydro power in a decentralized way during the monsoon season, and meeting lean season requirements through small storage, solar or other thermal options. Net energy analyses incorporating biomass energy lost in submergence show that maximization in net energy at a site is possible, if the hydroelectric generation capacity is adjusted according to the seasonal variations in the river’s water discharge. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Catchment area; Electric energy; Hydro power; Million units (m kWh); Precipitation; Run-of-river plants; Small hydro plants; Stream flow

1. Introduction

Hydraulic potential is the combination of the possible flows and the distribution of gradients, and the hydraulic resource is that fraction of the hydraulic potential which is still accessible after economic considerations. Hydro power owes its position as a renewable resource to the varying, but more or less continuous flow of a certain amount of water in the stream. Hydro power is a precipitation-dependent resource and is thus subject to the uncertainties which this entails.

Industrialization created new requirements, which demanded increased power generating capacities. The capacities of hydro power plants become very large and now contribute significantly to the State’s and National demand. Unfortunately, the cost of exploiting water power is vigilance in ensuring the environment is not irreparably damaged and the life of the river continues to flourish. This demands considerable care and attention in the planning process.

Mini, micro and small hydro plants (Appendix A) combine the advantages of large hydro plants on one hand and decentralized power supply on the other. These can divert only potential energy of the water which would have been dissipated to no benefit in the natural flow. The disadvantages associated with large hydro power plants, high transmission costs, environmental costs of submergence of prime lands (forests, crop lands,

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etc.), displacement of families etc., are not present in the case of small plants. Moreover, the harnessing of local resources, like hydro energy, being of a decentralized nature, lends itself to decentralized utilization, local implementation and management, rural development mainly based on self reliance and the use of natural, local resources. The domain where these plants can have potential impact on development is domestic lighting and stationary motive power for diverse productive uses like water pumping, wood and metal work, grain mills, agro processing industries, etc.

2. Area under consideration

Uttara Kannada District located in the mid-western part of Karnataka state (Fig. 1) is selected for this study. It lies 74° 9′ to 75° 10′ east longitude and 13° 55′ to 15° 31′ north latitude and extends over an area of 10 291 sq km, which is 5.37% of the total area of the state, with a population above 12 lakhs. It is a region of gentle undulating hills, rising steeply from a narrow coastal strip bordering the Arabian sea to a plateau at an altitude of 500 m, with occasional hills rising above 600 to 860 m. According to the recent landsat imageries, of the 10 291 sq km geographical area, 67.04% is under forest, 1.94% under paddy and millet cultivation, 1.26% under coconut and areca garden, 1.94% under rocky outcrops and the balance 27.82% is under habitation and reservoirs. There are four major rivers—Kalinadi, Bedthi, Aghnashini and Sharavathi. Besides these, many minor streams flow in the district.

This district with 11 taluks can be broadly categorized into three distinct regions—coast lands (Karwar, Ankola, Kumta, Honnavar and Bhatkal taluks), mostly forested Sahyadrian interior (Supa, Yellapur, Sirsi and Siddapur taluks) and the eastern margin where the table land begins (Haliyal, Yellapur and Mundgod taluks). Climatic conditions ranged from arid to humid due to physiographic conditions ranging from plains, mountains to coast. This large variety of natural conditions provides the basis for generalization of the theoretical probability distributions for annual precipitation. Among the four rivers, the hydro potential of Kali and Sharavati has been tapped already for power generation. The completed large scale projects have caused serious environmental damage in the form of submergence of productive natural virgin forests, horticulture and agricultural lands, etc.

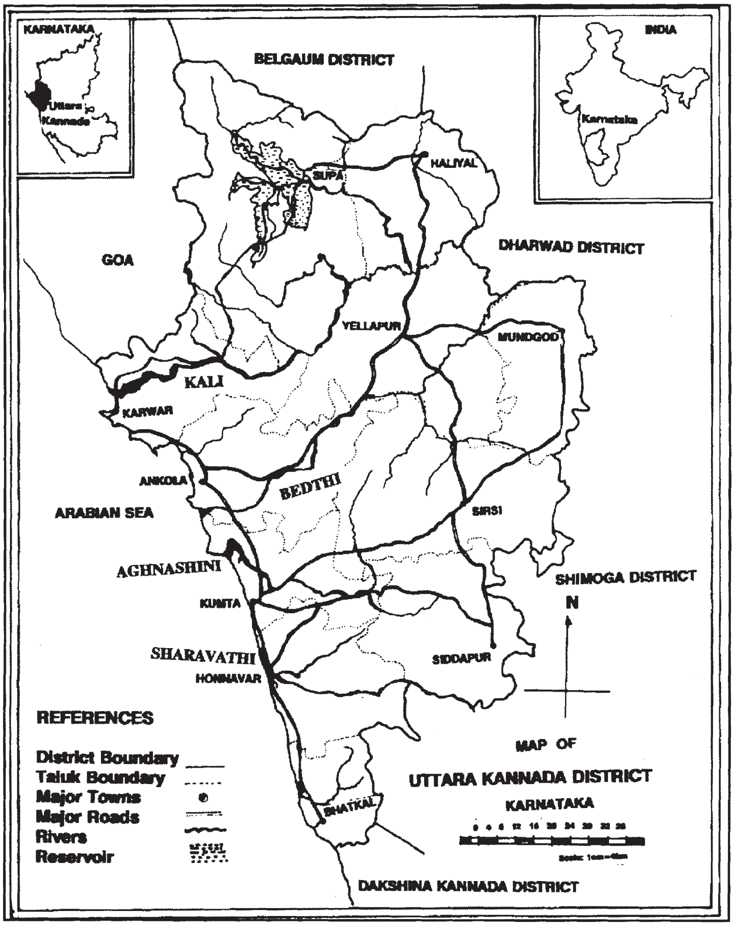

Fig. 1. Uttara Kannada District, Karnataka.

In view of these, we assess the potential of the Bedthi and Aghnashini rivers and explore ecologically sound means of harnessing the hydro energy.

3. Criteria for site selection

The choice of site is based on a close interaction between the various conditions like the pattern of the stream, integrity of the site works, environmental integration, etc. It is necessary to establish the inventory of energy demand in various sectors and assessment of various other sources like solar, biomass, wind, etc. Various factors considered while estimating hydro potential are: (1) the head; (2) hydrological pattern: defined from measurements or from inter-relationships between effective rain and discharge; (3) usage of water, upstream of the intake to determine the flow which is available, and downstream to determine the effects of diverting the water from present and future uses; (4) distance from the intake to the power station and from the power station to the consumer site; and (5) size of the scheme involved and evaluation of their stability depending on various lithological, morphological and topographical conditions.

4. Objectives

The objectives of this endeavour are to assess the potential of:

1. The streams based on 18 months field survey carried out in the basin of the Bedthi river;
2. The streams in the Bedthi and Aghnashini river basins based on precipitation and topographical information, and to explore an environmentally sound storage option.

5. Methodology

The hydrology of the river and streams under consideration were studied by:

1. Reconnaissance study: an exploratory survey was carried out in all streams which satisfy the above listed criteria and with water head greater than 3 m;
2. Feasibility study: this involved measurement of the catchment area and stream discharge for a substantial period of time.

5.1. Measurement of catchment area

Catchment boundaries are located using the contour lines on a topographical map. Boundaries are drawn by following the ridge tops which appear on topo maps as downhill pointing V-shaped crenulations. The boundary should be perpendicular to the contour lines it intersects. The tops of mountains are often marked as dots on a map, and the location of roads which follow ridges are other clues. The catchment area thus marked/traced is measured directly from the marked maps using a planimeter.

5.2. Stream discharge

Both direct and indirect methods were carried out. The indirect method is tried in order to assess the potential of ungauged streams.

5.2.1. Direct estimation of flows at site

Stream discharge is the rate at which a volume of water passes through a cross-section per unit of time. It is usually expressed in units of cubic meters per second (m^3/s). The velocity–area method using a current meter is used for estimating discharge. The cup type current meter is used in a section of a stream, in which water flows smoothly and the velocity is reasonably uniform in the cross-section. This measurement is carried out for three consecutive days every month for 18 months in order to take into account day-to-day fluctuations and seasonal variations. Five readings are recorded each time and the mean value is computed.

5.2.2. Indirect estimation of flows at site

Runoff is the balance of rain water, which flows or runs over the natural ground surface after losses by evaporation, interception and infiltration. The yield of a catchment area is the net quantity of water available for storage, after all losses, for the purpose of water resource utilization and planning. The runoff from rainfall was estimated by (1) the empirical formula and (2) the rational method.

1. Empirical formula: the relationship between runoff and precipitation is determined by regression analyses based on our field data.
2. Rational method: a rational approach is used to obtain the yield of a catchment area by assuming a suitable runoff coefficient.

$$\text{Yield} = C^*A^*P$$

where C is runoff coefficient, A is catchment area and P is rainfall. The value of 'C' varies depending on the soil type, vegetation, geology, etc. [1], from 0.1 to 0.2 (heavy forest), 0.2 to 0.3 (sandy soil), 0.3 to 0.4 (cultivated absorbent soil), 0.4 to 0.6 (cultivated or covered with vegetation), 0.6 to 0.8 (slightly permeable, bare) to 0.8 to 1.0 (rocky and impermeable).

This involved (i) analyses of 90 years' precipitation data collected from the India Meteorological Department, (ii) computations of discharge by the empirical/rational method based on precipitation history of the last 90 years and comparison with the values obtained by actual stream gauging, and (iii) computation of discharge and power in ungauged streams by the empirical/rational method in the Bedthi and Aghnashini basins.

Computation of power and total energy available in all streams.

6. Analyses of data and discussion

6.1. Rainfall

The response of watershed to precipitation is the most significant relationship in hydrology. The complexity of the rainfall–runoff relationship is increased by the areal variations of geological formations, soil conditions and vegetation, and by the areal and time variations of meteorological conditions [2]. Vegetation influences the rainfall–runoff relationship not only through interception and surface detention, but also by its effect on the impact energy of rainfall, which may initiate turbulence in overland flow and increase erosion.

The extent to which a stream/river is developed for energy depends on their flow, design of plant, etc. Precipitation and river flow are governed by chance phenomena, that is, there are so many causes at work that the influence of each cannot be readily identified. Therefore, statistical and probability methods are applied to describe this hydrological phenomena [3]. An attempt is made in this section to (1) find theoretical probability functions of best fit relationships to distributions of annual precipitation and (2) find whether there is any relationship in year-to-year precipitation, and to see whether this data reveals any significant trend.

Most rainfall records are obtained by periodic observation of gauges. The usual interval is 24 h. In this district, the India Meteorological Department has three observatories in coastal belts at Karwar, Honnavar and Shirali, where various parameters like temperature, humidity, rainfall, solar radiation and cloud cover are recorded at regular intervals through automatic weather stations. In 27 rain gauge stations distributed all over the district rainfall is recorded manually, usually through Tahsildar's office. All precipitation records collected from various agencies are used with the realization that the records obtained (at different elevations) are indicative of average precipitations.

6.2. Mean rainfall of the region

The inter annual variability of the yearly and monsoon rainfall has considerable impact on activities like agriculture, water management and energy generation. In view of this, monthwise rainfall data collected all over the district and subsequent annual rainfall variability computed have been looked at in greater detail. Ankola, Bhatkal, Kumta, Karwar, Sirsi, Siddapur and Yellapur taluks' rainfall variability were studied for 90 years, beginning from 1901. However, the data were studied in Haliyal taluk for 22 years, Supa taluk for 27 years and Honnavar taluk for 62 years. The annual average rainfall and standard deviation computed for each taluk based on these data are listed in Table 1. This shows that Bhatkal receives the highest rainfall, of the order 3942 (avg) ± 377 (SD) mm and Haliyal, least rainfall with 1174 (avg) ± 166 (SD) mm. The coefficient of variation computed to see the relative variability of precipitation data is listed in Table 2. The coefficient of variation ranges from 0.085 (Karwar) to 0.1105 (Honnavar) in the coastal region, 0.0810 (Yellapur) to 0.1217 (Siddapur) in the Sahyadrian interior, and 0.1415 (Haliyal) to 0.2083 (Mundgod) in the plains.

6.3. Properties of observed data

As indicated in Fig. 2, the coastal taluks receive the highest mean annual rainfall of 3132 to 3942 mm. The hilly taluks follow the coastal taluks with 2470 to 2997 mm. The taluks in the plains get the least rainfall. It is seen that the ranges of annual precipitation are very distinct, indicating the large variety of the climatic and physiographic area of the district. The south west monsoon constitutes 88 to 90% of total precipitation in these taluks. Various statistical tests are carried out for annual rainfall data for each taluk to find out whether the rainfall regime in any taluk follows a particular trend, whether there is any relationship among variables and to see whether the rainfall during any particular year depends on previous year/s. The statistical runs test (runs above mean and below mean, runs up and runs down) conducted for annual rainfall data for each taluk and the district suggests that the variables are independent of each other.

6.4. Statistical tests: goodness-of-fit test

According to properties of observed data, the distribution functions of best fit to observed frequency of annual precipitation should be a bell-shaped but skewed curve. Screening of the applicable functions with respect to the criteria required, their convenience in usage in mass computation, and the experience already obtained in applying them in this kind of analysis, as listed in the literature [4,5], lead to the selection of (a) normal density function, (b) log normal and (c) gamma.

To test the theoretical probability distribution functions for goodness of fit to observed data, the data is classified into mutually exclusive and exhaustive categ-

Table 1
Annual rainfall—Talukwise

Taluk	Years	Pre-monsoon		Southwest monsoon		Northeast monsoon		Annual rainfall			
		Avg	SD	Avg	SD	Avg	SD	Avg	SD	Min	Max
Ankola	90	125	80	3084	251	204	67	3413	273	2915	4265
Bhatkal	90	162	107	3514	344	257	95	3942	377	3062	4987
Haliyal	22	126	38	907	121	141	35	1174	166	899	1452
Honavar	62	126	82	3094	313	216	67	3436	380	2520	4090
Karwar	90	140	82	2794	216	198	64	3132	267	2548	3736
Kumta	90	140	84	3445	920	222	83	3566	364	2759	4450
Mundgod	90	145	60	887	203	181	53	1235	257	846	2078
Siddapur	90	110	50	2635	417	188	54	2997	365	2206	3951
Sirsi	90	96	34	2150	242	183	47	2430	263	1743	3037
Supa	27	35	38	2305	302	117	37	2485	219	2047	2803
Yellapur	90	100	30	2200	214	170	49	2470	200	1879	2878

Table 2
Talukwise computation of coefficient of variation (COV)

Taluk	Region type	COV
Karwar	Coastal region	0.085
Ankola		0.080
Kumta		0.102
Honavar		0.110
Bhatkal		0.096
Supa	Sahyadrian interior	0.088
Yellapur		0.081
Sirsi		0.108
Siddapur		0.122
Mundgod	Plain region	0.208
Haliyal		0.142

ories of class intervals. The chi-square test is used as a measure of goodness of fit of the theoretical probability distributions. If the probability of a hypothesized function is less than the assigned level of significance, then the function would be acceptable as a good approximation to the distribution of a considered sample. The normal and log-normal distributions are fitted to the distribution of annual precipitation data of taluks in Uttara Kannada district. It is found that the departure between normal and observed distribution would give the probability of chi-square less than 0.95 for Siddapur, Yellapur, Karwar, Mundgod, Haliyal and Supa taluks. While for Ankola, Kumta, Sirsi, Bhatkal and Honnavar taluks, annual precipitation data follows log-normal distribution, as the departure between observed and log-normal distribution has the probability of chi-square 0.32,

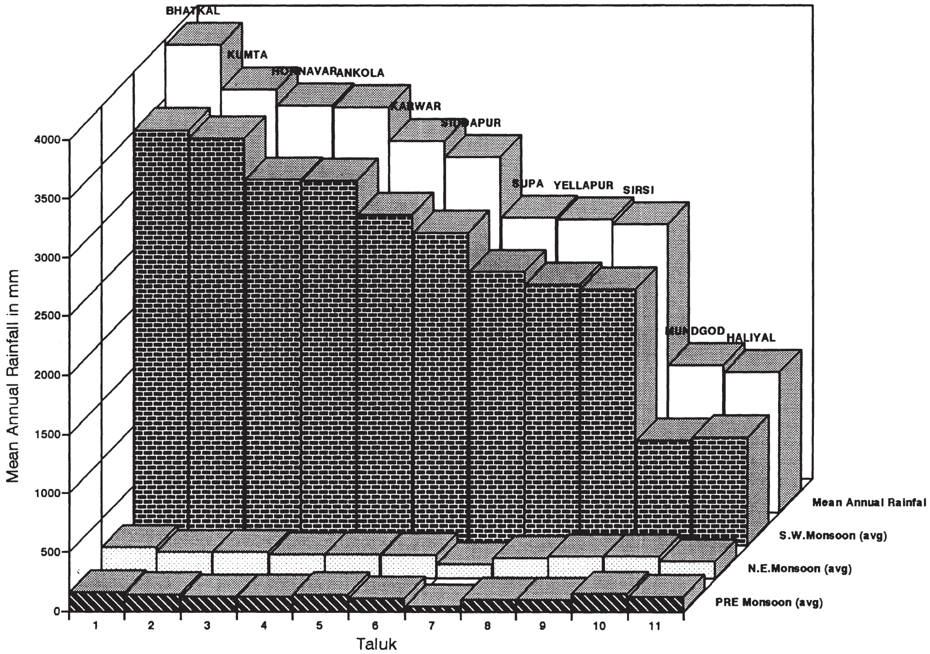

Fig. 2. Mean annual rainfall (Talukwise) Uttara Kannada District.

0.55, 0.82, 0.44 and 0.79 (all are less than 0.95, accepted at the 95% level of significance). The smaller the value of probability, the smaller is the departure between theoretical and observed distributions, and the better the theoretical function fits an observed distribution.

These analyses illustrate that altitude and distance from the sea cannot explain the differences between the distributions of annual precipitation of taluks. For example, two neighboring taluks in the coastal belt, Ankola and Karwar (or in the interior, Siddapur and Sirsi), give two different distributions. There may be certain other factors, such as latitude, temperature, evaporation, prevailing wind direction of moist air masses, governing the difference in distribution. However, analyses show that regional characteristics especially do not favour the use of one of the probability functions in fitting the observed distributions of annual precipitation.

6.5. *Stream flow and precipitation*

Distributions of annual river and stream flows are affected by physiographic factors of a watershed area apart from its precipitation. The literature regarding watershed response can be classified into two general groups. The majority of the research has dealt with obtaining the time distributions of direct surface runoff at a point, given the volume and distribution of the effective rainfall. The remaining part deals with the total rainfall–runoff relationship, including estimation of the volume of effective rainfall, considering loss functions experienced by storm rainfall. Studies regarding the conversion of effective rainfall to hydrographs of stream flow at the catchment outlet stem primarily from unit hydrograph theory. The theory has been modified, applied, verified, and used for analysis and synthesis. The concept of the instantaneous unit hydrograph along with various storage and routing ideas has led to numerous theoretical response models. On the other hand, few rainfall–runoff models have been investigated with emphasis on the conversion of rainfall to effective runoff.

Stream flow and ecology are both affected by catchment conditions. Changes in stream discharge and sediment loading, caused by the modification of the catchment area are reflected in variations in the rate of sediment transport, channel shape and stream pattern. Responses to a change may be immediate, delayed or dependent upon a critical factor reaching a threshold level. It is necessary to know the response of catchment/watershed to rainfall in order to design structures, such as overflow spillways on dams, flood-protection works, highway culverts and bridges [6]. The rate at which runoff moves towards the stream depends on the drainage efficiency of the hill slopes. Drainage efficiency is influenced by the slope and length of upland surface, its micro topography, the permeability and moisture content of the soil, subsurface geology and vegetation cover. The hydro potential of each stream is assessed so as to have micro, mini or small hydro power plants.

7. Feasibility study of mini, micro and small hydro sites

The catchment area for streams are obtained from the Survey of India toposheets. Stream gauging is done with both direct and indirect methods.

7.1. *Catchment area*

Catchment area measured from the marked toposheets using planimeter for the streams in Bedthi and Aghnashini river basins are listed in Tables 3 and 4, respectively. Along the Bedthi river course drops at various points have been identified: Kalghatgi (80 m), Kaulgi Halla (64 m), major drop at Magod (of about 340 m), and the lowest drop 8.5 m is in Ankola taluk, about 129 km from Kalghatgi. Numerous streams join the river along its course from Kalghatgi. Major streams with good drops (head) are Shivganga (119 m), Handinadi (230.50–318.50 m) and Matti gatta (270 m). The Aghnashini river has major drops at Unchalli (360 m) and the major streams are Benne (400 m drop), Bhimavara (290 m), Mudanalli (270 m), etc.

The average channel slope (S_c) is one of the factors controlling water velocity, while the slope of the catchment (S_b) influences surface runoff rates. These two parameters give an idea about the nature of a stream. Hence S_c and S_b are computed and listed in Tables 3 and 4. Magod has a slope of 61.34°. The Shivganga and Mattigatta streams of the Bedthi catchment have slopes 43.83° and 40.03°, while Muregar and Boosangeri have slopes of 6.27° and 2.29°. The Muregar jog has a catchment of 25.97 sq km, while Boosangeri has 11.29 sq km. Stream gauging at regular intervals is carried out in Muregar, Boosangeri, Vanalli and Shivganga.

7.2. *Catchment shape*

The shape of the Boosangeri catchment is short and wide (fan shaped), while Muregar, Mattigatta and Shivganga catchments are elongated.

7.3. *Stream flow measurement (direct method) and computation of power (kW)*

Stream gauging is carried out using a current meter every month. Stream discharge ranges from 1.12 (August) to 0.015 cum/s (in February) for Boosangeri. In the case of Muregar, it ranges from 1.395 to 0.026 cum/s. This indicates that streams of this kind are sea-

Table 3
Catchment area, stream slope, catchment slope computed for various streams of Bedti river

	Lat From	Lat To	Long From	Long To	Catchment area (sq km)	Height (m)	Stream slope (degrees)	Catchment slope (degrees)
Magod	14°45′		74°45′		2084.46	340.00	61.35	68.46
Shivganga	14°45′	14°50′	74°46′		88.48	119.00	55.71	60.64
Arumatti Halla	14°40′	14°45′	74°29′		16.50	145.00	32.80	40.67
Handimadi	14°40′	14°45′	74°28′		27.29	230.50	86.52	15.44
H Nadhi 2	14°40′	14°45′	74°28′		23.16	318.50	23.01	27.68
H Nadhi 3	14°40′	14°45′	74°28′		24.55	255.00	17.94	22.53
Varangudda	14°40′	14°45′	74°28′		25.60	240.00	37.57	44.56
Talagudde	14°35′	14°40′	74°22′		27.29	95.00	19.06	24.73
Hirehalla	14°35′	14°40′	74°29′		66.82	288.50	23.53	30.14
Motigudda	14°35′	14°40′	74°30′		35.92	345.00	34.61	38.19
Malgaon	14°40′	14°45′	74°33′		20.25	60.00	23.58	21.20
Heggarni	14°40′	14°45′	74°30′	74°35′	26.42	220.00	64.54	67.38
Aladbail	14°40′	14°45′	74°30′	74°35′	16.24	190.00	32.35	40.18
Kotegudda	14°40′	14°45′	74°30′	74°35′	13.16	240.00	60.19	61.51
Kanchikeri	14°40′	14°45′	74°30′	74°35′	13.40	14.00	43.03	51.22
Bairekoppa	14°40′	14°45′	74°30′		12.60	40.00	21.80	14.93
Gubargadda	14°35′	14°40′	74°30′	74°35′	40.26	230.00	83.67	84.64
Vadgar	14°35′	14°40′	74°30′	74°35′	22.70	230.00	44.08	45.30
Harolli	14°35′	14°40′	74°30′	74°35′	14.40	135.00	34.02	29.54
Hubbanmane	14°35′	14°40′	74°30′	74°35′	12.60	185.00	50.96	50.19
Marnadi	14°35′	14°40′	74°30′	74°35′	18.20	270.00	51.80	54.08
Devanmane	14°35′	14°40′	74°30′	74°35′	24.60	275.00	36.94	45.08
Asnil	14°35′	14°40′	74°30′	74°35′	20.20	245.00	56.45	56.62
Asolli	14°35′	14°40′	74°30′	74°35′	20.70	235.00	38.66	43.70
Kalmane	14°35′	14°40′	74°30′	74°35′	28.90	235.00	49.60	50.96
Kumbhatt	14°50′	14°55′	74°45′		9.85	180.00	55.22	60.40
Dabguli (Panasguli)	14°50′	14°55′	74°35′	74°40′	34.68	220.50	14.96	16.01
Mulepal	14°50′	14°55′	74°35′	74°40′	18.60	180.00	28.98	33.28
Mogadde Halla	14°50′	14°55′	74°35′	74°40′	39.65	280.00	13.38	16.84
Garge Halla	14°45′	14°55′	74°30′	74°35′	29.72	230.00	22.69	23.58
Ramanguli	14°45′	14°55′	74°30′	74°35′	21.03	90.00	16.67	10.08
Barehalla	14°45′	14°50′	74°30′	74°35′	39.41	215.00	24.35	29.92
Benguli	14°45′	14°50′	74°30′	74°35′	20.46	330.00	51.50	54.89
Mulemane	14°45′	14°50′	74°30′	74°35′	13.46	230.00	47.27	48.48
Matti Gatta	14°35′	14°45′	74°35′	74°40′	32.13	270.00	30.43	30.54
Vaidyaheggar	14°45′	14°50′	74°35′	74°40′	11.43	230.00	56.89	58.00
Kaigadi	14°45′	14°50′	74°40′	74°45′	12.60	230.00	42.61	49.56
Achave Stream	14°35′	14°50′	74°35′	74°40′	62.55	230.00	78.69	78.69
Kalalegadde	14°35′	14°40′	74°35′	74°45′	40.26	40.00	83.94	83.94

sonal. Power generated during June to September is sufficient to meet the energy needs of the nearby villages. Power computed for these streams is shown in Fig. 3.

Stream flow measurement (indirect method)—empirical formula: the runoff (R) and precipitation (P in cm) relationship determined by regression analyses based on our field data $R = 0.85*P + 30.5$, with $r = 0.89$ and the percentage error is 1.2.

7.4. Rational method

In order to estimate the hydro power potential of ungauged streams, either the rational or empirical relationship of runoff and precipitation is used. In the rational method, monthly yield is derived by assuming a suitable runoff coefficient (which depends on catchment type). For each site, Yield ($Y = C*A*P$) is computed with the knowledge of catchment area (A), catchment coefficient (C) and precipitation (P). An attempt has been made to compute the monthly yield from catchments by this method, and subsequently the power that could be harvested from the streams. Estimated monthly power by the indirect method is shown pictorially in Fig. 4. This corresponds with the power computed by the direct method (of the gauged streams Boosangeri and Muregar). Hence, we use the rational method to compute hydro power of ungauged streams. This study explores the possibility of harnessing hydro potential in an ecologically sound way (by having run-of-river plants with no storage options) to suit the requirements of the region.

Table 4
Catchment area, stream slope, catchment slope computed for various streams of Aghnashini river

Feasible sites	Latitude		Longitude		Catchment area	Height	Stream slope	Catchment slope
	From	To	From	To				
Unchalli	14°20′	14°25′	74°45′	74°50′	605.67	360.00	35.54	26.04
Benne	14°25′	14°32′	74°35′	74°40′	140.75	400.00	23.96	17.87
Melinsalve	14°30′	14°37′	74°35′	74°40′	20.60	93.75	11.17	12.66
Koregudda	14°30′	14°35′	74°35′	74°40′	12.62	30.00	11.31	10.08
Kokande	14°30′	14°35′	74°35′	74°40′	14.60	70.00	17.28	19.57
Mundagar	14°30′	14°35′	74°35′	74°40′	24.80	60.00	11.31	11.72
Salikoppa	14°25′	14°30′	74°35′	74°40′	18.90	15.00	36.87	84.29
Ne Morse	14°25′	14°30′	74°38′	74°45′	12.80	276.50	47.88	50.81
Bhimavara	14°25′	14°30′	74°38′	74°45′	18.60	290.00	44.03	46.85
Halebail	14°25′	14°30′	74°35′	74°40′	9.20	280.00	44.03	63.94
Bandal	14°30′	14°35′	74°35′	74°40′	21.80	210.00	34.99	43.03
Nigodu-Kilar	14°20′	14°30′	74°45′	74°55′	28.00	67.25	24.81	22.62
Keremane	14°20′	14°25′	74°40′	74°45′	42.50	218.00	19.97	25.02
Balur	14°20′	14°25′	74°40′	74°45′	36.80	222.00	27.58	33.38
Birlamakki	14°20′	14°25′	74°40′	74°45′	12.60	226.00	56.43	61.82
Markodi Halla	14°25′	14°30′	74°40′	74°45′	48.90	85.50	6.10	20.72
Huldevarakodalu	14°22′	14°28′	74°35′	74°40′	48.90	85.50	6.10	20.72
Huldeva	14°22′	14°28′	74°35′	74°40′	10.20	170.00	51.03	58.76
Shavemane	14°22′	14°28′	74°35′	74°40′	18.40	210.00	43.03	58.76
Mudanalli	14°22′	14°28′	74°35′	74°40′	22.60	270.00	44.47	49.33
Basolli	14°22′	14°28′	74°35′	74°40′	14.40	14.00	34.99	30.96
Santeguli	14°22′	14°28′	74°30′	74°35′	33.20	190.00	26.87	26.46
Vadgeri	14°22′	14°30′	74°40′	74°45′	14.20	209.00	37.24	44.12
Abbigadde	14°22′	14°30′	74°40′	74°45′	18.40	200.00	45.00	51.71
Hukkalli	14°22′	14°30′	74°40′	74°45′	20.40	220.00	48.81	54.18
Tingar	14°25′	14°30′	74°30′	74°40′	16.20	190.00	32.35	30.02
Ambiguli	14°25′	14°30′	74°30′	74°40′	14.80	210.00	30.96	37.30
Holavali	14°25′	14°30′	74°30′	74°40′	12.60	230.00	53.90	61.33
Kanakale	14°25′	14°30′	74°30′	74°35′	8.60	14.00	48.24	56.19
Kavaladi	14°25′	14°30′	74°30′	74°35′	8.80	190.00	59.37	58.92
Korebail	14°25′	14°30′	74°30′	74°35′	19.60	240.00	34.44	35.90
Shiragunj	14°25′	14°30′	74°30′	74°35′	12.80	95.00	32.35	21.80
Chandikanadi	14°25′	14°30′	74°25′	74°32′	24.80	145.00	21.14	17.75
Bogorbail	14°25′	14°30′	74°25′	74°32′	11.60	65.00	27.47	25.64
Khaire	14°25′	14°30′	74°25′	74°32′	22.60	245.00	31.49	32.35
Kudirahalla	14°25′	14°35′	74°22′	74°28′	50.44	171.50	19.85	22.15
Bargi	14°25′	14°35′	74°22′	74°28′	9.60	14.00	44.03	40.18

The Sirsi, Siddapur and Yellapur taluks in hilly terrain amidst evergreen forests with a large number of streams are ideally suitable for micro, mini or small hydro power plants. Monthly stream gauging at Muregar and Boosangeri has revealed that mini hydro power plants could be set up at these sites. The stream at Muregar is perennial, with a flow of about 0.26 m^3/s during summer, and power of the order of 10–20 kW could be generated, while during the monsoon power of 300–400 kW could be harnessed.

Computations of discharge by the empirical or rational method, considering precipitation history of the last 100 years, and the subsequent power calculated is in conformity with the power calculations done based on stream gauging. Based on this field experience of gauged sites, an attempt has been made to compute water inflow (using the indirect method), hydraulic power available, and energy that could be harnessed monthly for all ungauged streams in the Bedthi and Aghnashini river catchments. The energy potentials of all streams in these catchments are listed in Tables 5 and 6, respectively. It is estimated that we can generate about 720 and 510 million kWh from various streams in the Bedthi and Aghnashini catchments.

The potential assessment shows that most of the streams are seasonal and cater for the needs of local people in a decentralized way during the monsoon. This ensures a continuous power supply during the heavy monsoon, which otherwise gets disrupted due to dislocation of electric poles due to heavy winds, and the falling of trees/branches on transmission lines, etc. A detailed household survey of villages in hilly areas shows that, during the monsoon, people have to spend at least 60 to 65% of the season without electricity from

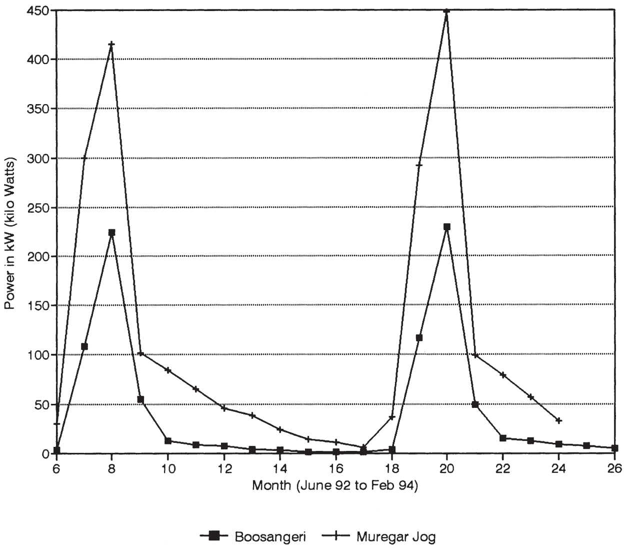

Fig. 3. Estimated power in Muregar and Boosangeri (based on field experiments).

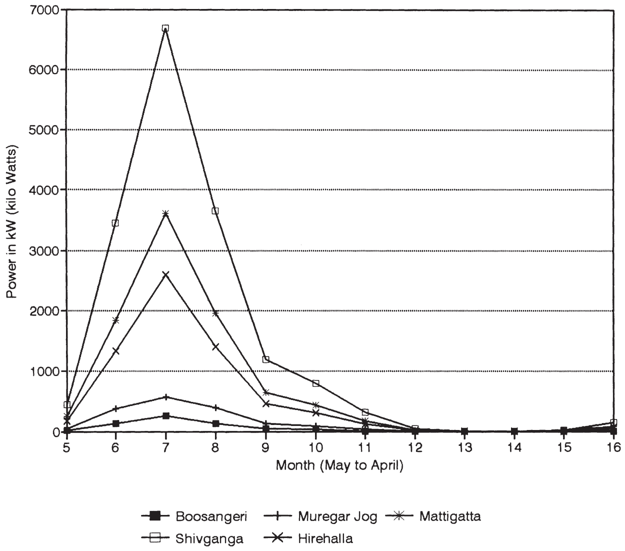

Fig. 4. Estimated power in Muregar and Boosangeri Jog (rational method).

centralized supply due to environmental problems. This demands for alternatives to meet the region’s requirement during the lean season. This exercise provides insight into the regional energy requirement through integrated approaches like harnessing hydro power in a decentralized way during seasons and meeting the lean season requirement through small storage option, solar or other thermal options. In view of this, an ecologically sound alternative is proposed, which would generate maximum electricity during the monsoon and sufficient electricity during the lean season by storing enough water to meet the region’s requirements.

8. Design of a reservoir with energy and ecology constraints

Nature does not meet the demand for water at all times and in all places. Due to environmental impacts associated with large reservoirs, it has become necessary to estimate their proper sizes to meet the target demand of a region. The design of storage systems for power generation in a hilly terrain is constrained mainly by ecological factors these days. The negative aspects of hydroelectric projects necessitate the minimizing of the submergence area and are subject to reasonable costs, minimum or no wastage of water and seasonal constraints (the region receives maximum rainfall during the south-west monsoon).

8.1. Design assumptions and parameters—scenario creation

1. Assumptions: detailed geological and topographical investigations carried out to determine the best site for the dam, pressure shaft alignment, power house location, etc. by the Department of Mines and Geology and Karnataka Power Corporation Limited [7], can be used for implementing this design.
2. Parameters: input data consists of site specific (discharge, water yield, generation head, evaporation rate, seepage rate etc.), technical (efficiency of turbine and generator, and dependability norm for storage capacity, load factor, etc.) and economic data (civil construction costs for various types and heights of dam, cost of electrical machineries of various capacities, environmental costs, rehabilitation costs, etc.).
3. Decision variables: these are to determine the optimum storage capacity, installed generation capacity and seasonal power drafts, to maximize net energy availability in the region (objective function) subject to seasonal hydrological constraints, and minimize costs and submergence area.

8.2. Net energy model—parametric optimization

The broad outline of an optimization model for exploiting a river for hydro power and irrigation, incorporating energy costs and net increase in yield due to irrigation, with constraints on arable area and crop water requirements and seasonal variations in precipitation, was formulated earlier by Subramanian [8]. On the same lines, with detailed engineering design and quantification of data, the parametric optimization approach is used, to find out the alternatives for the Magod site, to get maximum energy subject to the ecological constraints.

The parametric model is solved for various scenarios

Table 5
Estimated energy ('000 units) in ungauged streams of Bedthi catchment area

Streams	April	May	June	July	August	September	October	November	Total
Arumatti Halla	0.60	5.39	49.69	91.62	52.34	18.86	13.69	4.83	237.02
Handinadi	5.73	30.75	230.66	421.41	239.47	91.36	68.28	28.14	1115.80
Varangudda	1.40	9.33	77.84	142.92	81.45	30.14	22.18	8.46	373.72
Talagudde	14.71	95.64	789.15	1448.24	825.13	306.21	225.68	86.72	3791.48
Hirehalla	144.66	784.94	5924.46	10827.26	6153.75	2343.31	1749.60	717.87	28645.85
Motigudda	79.52	476.41	3786.89	6937.88	3948.90	1481.03	1097.41	433.60	18241.64
Malgaon	5.59	42.09	367.74	676.56	386.02	141.05	103.11	37.94	1760.09
Heggarni	32.38	213.18	1768.28	3245.93	1849.60	685.41	504.76	193.21	8492.75
Aladbail	11.01	100.24	928.81	1712.91	978.69	352.23	255.43	89.78	4429.09
Kotegudda	7.42	94.56	944.56	1746.96	999.78	353.31	253.67	83.94	4484.21
Kanchikeri	4.62	56.62	561.39	1038.00	593.95	210.26	151.11	50.31	2666.26
Gubbargadda	383.45	1950.83	14172.70	25851.80	14676.60	5654.21	4245.84	1790.20	68725.63
Kumbhatt	0.34	45.09	524.11	974.34	559.26	191.15	134.65	39.21	2468.14
Datguli	48.43	292.63	2335.73	4280.07	2436.40	912.69	675.87	266.23	11248.05
Mulepal	14.15	113.38	1011.34	1862.23	1063.06	386.34	281.63	101.98	4834.11
Mogadde Halla	73.69	431.94	3396.50	6219.52	3538.98	1331.43	988.11	393.53	16373.71
Garge Halla	40.51	255.78	2083.46	3821.35	2176.46	810.63	598.53	232.24	10018.95
Garge Halla	40.51	255.78	2083.46	3821.35	2176.46	810.63	598.53	232.24	10018.95
Ramanguli	8.99	66.17	573.32	1054.41	601.48	220.27	161.22	59.71	2745.59
Ramanguli	8.99	66.17	573.32	1054.41	601.48	220.27	161.22	59.71	2745.59
Barehalla	56.13	329.43	2592.06	4746.61	2700.92	1015.96	753.91	300.12	12495.16
Benguli	31.33	234.48	2044.00	3760.12	2145.28	784.36	573.60	211.43	9784.59
Benguli	31.33	234.48	2044.00	3760.12	2145.28	784.36	573.60	211.43	9784.59
Mulemane	7.72	93.61	926.55	1713.06	980.20	347.14	249.53	83.20	4401.02
Matti Gatta	53.26	328.47	2647.09	4852.77	2763.11	1032.25	763.35	298.56	12738.86
Hasehalla	184.77	970.35	7187.03	13122.37	7454.11	2854.72	2137.44	888.94	34799.72
Vaidyaheggar	3.62	73.37	782.11	1449.85	830.85	289.28	205.96	64.59	3699.64
Kaigadi	5.98	85.04	865.36	1601.56	916.93	322.63	231.08	75.31	4103.88
Bili Halla	148.90	794.56	5940.22	10850.94	6165.52	2354.53	1760.47	727.29	28742.43
Bili Halla	148.90	794.56	5940.22	10850.94	6165.52	2354.53	1760.47	727.29	28742.43
Songi Mane	22.88	161.36	1376.14	2529.16	1442.19	530.40	389.07	145.83	6597.03
Achave Stream	106.72	583.19	4419.33	8078.13	4591.79	1746.43	1303.18	533.17	21361.93
Vatehalla	15.72	89.77	696.69	1274.96	725.20	273.88	203.65	81.89	3361.77
Kalalegadde	10.74	62.76	492.76	902.26	513.37	193.23	143.44	57.19	2375.76
Pattanadahall	38.07	200.94	1492.58	2725.60	1548.40	592.47	443.41	184.03	7225.50
Shalmala	127.19	675.14	5032.03	9190.58	5221.63	1995.92	1493.02	618.15	24353.68
Anegundi	14.71	89.62	718.12	1316.13	749.28	280.37	207.51	81.51	3457.24
Manigeri	5.38	43.49	388.97	716.31	408.93	148.51	108.22	39.10	1858.90
Hosahalli	10.29	67.77	562.20	1032.01	588.06	217.91	160.47	61.42	2700.13
Sadashivalli	20.57	123.42	981.76	1798.72	1023.81	383.90	284.43	112.32	4728.95
Nilkani	9.98	63.81	522.72	958.99	546.28	203.14	149.87	57.91	2512.69
Gunjavati	46.70	245.41	1818.28	3319.95	1885.90	722.17	540.69	224.81	8803.92
Tandi Halla	10.95	66.18	528.41	968.28	551.19	206.46	152.89	60.21	2544.57
Kaulgi Halla	79.49	424.44	3174.31	5798.58	3294.79	1258.11	940.63	388.50	15358.85
Majjige Halla	42.93	222.86	1639.14	2991.76	1699.11	652.10	488.77	204.29	7940.97
Mavinkatte	47.65	249.24	1841.73	3362.31	1909.81	731.93	548.22	228.38	8919.27
Devigadde	43.81	231.12	1716.38	3134.25	1780.54	681.35	509.95	211.68	8309.09
Koppadgadde	17.18	100.37	788.02	1442.89	820.99	309.01	229.38	91.46	3799.29
Bajankoppa	12.40	75.78	608.10	1114.58	634.56	237.35	175.62	68.91	2927.30
Bharni	11.98	73.70	593.25	1087.52	619.21	231.40	171.14	66.99	2855.19
Heggarni	8.32	53.18	435.60	799.16	455.23	169.28	124.89	48.25	2093.91
Magod Falls	4695.0	16435.5	161345.0	387522.4	170605.2	60538.7	43563.4	14620.8	859326.1
Chandmata	23.34	149.19	1221.85	2241.59	1276.88	474.86	350.34	135.39	5873.46

for optimal utilization of energy in the water and thermal energy in the region. The objective is to maximize the net energy available in the region, which is given by

$$E_{net} = Eh - E_{bio} \tag{1}$$

This model includes an equation which computes monthly hydro power production as a function of (a) the volume of water discharged, (b) the gross head of this water, and (c) the efficiency of the couple turbine generator. Hydro power is given by

Table 6
Estimated energy ('000 units) in ungauged streams of Aghnashini catchment area

Streams	April	May	June	July	August	September	October	November	Total
Melinsalve	32.39	73.82	877.53	1683.70	1046.48	280.42	103.11	31.19	4128.66
Koregudda	15.18	832.07	170.46	328.44	204.64	53.13	18.23	4.08	1626.24
Kokande	15.42	35.47	461.62	888.14	552.90	145.16	51.08	12.94	2162.73
Mundagar	25.99	59.04	677.78	1298.97	806.84	218.01	81.54	26.17	3194.34
Salikoppa	46.51	106.18	1286.50	2469.87	1535.66	409.69	149.25	43.62	6047.28
Ne Morse	50.52	116.80	1593.98	3070.89	1913.20	497.28	171.05	38.87	7452.58
Bhimavara gudda	88.10	201.22	2447.14	4698.64	2921.61	778.76	283.18	82.20	11500.83
Halebail	30.12	71.10	1149.52	2224.12	1389.07	349.44	111.02	14.53	5338.92
Bandal	77.82	177.16	2081.83	3992.89	2481.21	666.69	246.52	76.07	9800.19
Nigodu-Kilar	33.62	76.25	858.88	1645.01	1021.40	277.26	104.67	34.63	4051.71
Mattimane Halla	52.92	119.41	1272.41	2432.38	1508.59	415.26	161.14	57.94	6020.05
Markodinalla	33.66	76.11	829.87	1587.68	985.16	269.60	103.43	35.97	3921.47
Nigmandikai	23.31	53.16	635.86	1220.26	758.53	202.96	74.40	22.25	2990.73
Markodinalla	84.75	192.17	2164.75	4146.16	2574.38	698.81	263.82	87.29	10212.12
Amminalli	38.14	86.28	946.06	1810.32	1123.44	307.00	117.45	40.50	4469.20
Keremane	174.98	395.09	4241.24	8109.80	5030.56	1382.12	534.35	190.12	20058.27
Balur	151.78	343.12	3735.77	7146.82	4434.50	1213.98	466.07	162.44	17654.48
Birlamakki	40.35	93.35	1282.02	2470.31	1539.19	399.54	137.02	30.66	5992.43
Markodi Halla	80.05	180.56	1915.66	3661.45	2270.67	625.74	243.33	88.05	9065.52
Huldevarakodalu	21.83	51.12	776.28	1499.72	935.85	238.15	77.89	13.01	3613.87
Shavemane	62.92	143.74	1752.70	3365.56	2092.80	557.51	202.47	58.49	8236.19
Mudanalli	104.56	237.88	2776.20	5323.49	3307.63	890.20	330.29	103.13	13073.38
Basoli	30.26	69.62	910.33	1751.69	1090.56	286.04	100.43	25.20	4264.13
Santeguli	115.62	261.65	2881.99	5515.68	3423.20	934.40	356.69	122.18	13611.41
Vadgeri	44.29	101.98	1339.73	2578.30	1605.32	420.62	147.35	36.59	6274.17
Abbigadde	59.92	136.90	1669.24	3205.30	1993.14	530.96	192.83	55.70	7843.99
Hukkalli	75.10	171.18	2038.99	3912.42	2431.82	651.33	239.26	72.11	9592.20
Tingar	48.20	110.49	1393.10	2677.78	1666.10	440.49	157.40	42.62	6536.17
Ambiguli	47.14	108.36	1404.22	2701.34	1681.54	441.90	155.82	39.87	6580.19
Holavali	41.06	95.00	1304.71	2514.03	1566.43	406.61	139.44	31.20	6098.49
Kanakale	13.31	31.62	536.04	1038.26	648.84	161.87	50.33	5.20	2485.46
Kavaladi	18.85	44.69	745.00	1442.45	901.24	225.50	70.65	7.99	3456.36
Korebail	77.92	177.75	2135.84	4099.40	2548.44	681.19	249.16	73.94	10043.64
Shiragunj	17.36	40.13	547.66	1055.10	657.34	170.85	58.77	13.35	2560.56
Chandkanadi	62.81	142.68	1637.97	3139.19	1949.86	526.85	197.06	63.24	7719.65
Bogorbail	10.25	23.81	338.76	653.38	407.33	104.97	35.40	7.22	1581.11
Khaire	94.88	215.86	2519.14	4830.58	3001.37	807.77	299.70	93.58	11862.89
Kudirahalla	166.08	374.54	3964.26	7576.37	4698.29	1295.53	504.39	183.11	18762.57
Bargi	16.23	38.17	600.57	1161.26	725.00	183.28	58.96	8.65	2792.13
Benne	510.12	4033.00	51052.70	87307.16	42225.82	12838.77	8188.46	959.20	55085.70

$$P = 9.81 * Q * H \qquad (2)$$

The corresponding electricity produced $Eh = P*t*\eta$, where E is the electricity produced (in kilowatt hours), P is the hydraulic power (in kilowatts), t is the operating time (in hours) and η the turbine-generator assembly efficiency (between 0.7 and 0.85). Because of the estimates of the couple turbine-generator and gross height, this is only an approximate characterization of the energy harnessed for the purpose of illustration.

The monthly hydroelectricity generated in million units (million kWh) is given by

$$Eh_t = \Sigma 9.81 * D_t * H * \eta \qquad (3)$$

where $t = 1......12$, H is the average net generation head, η is the efficiency of the turbine-generator combination and D_t is the power draft from the reservoir during a month (million cubic meters, Mm^3). This can be written as

$$Eh_t = \Sigma k1 * D_t, \text{ where } k1 = 9.81 * H * \eta$$

This equation is decomposed to indicate seasonal draft.

$$Eh_t = \Sigma k1 * D_{tm} + \Sigma k1 * D_{td} \qquad (4)$$

where $tm = 1...4$, water drawn during monsoon months (June to September), and $td = 5...12$, water drawn during non-monsoon months (dry period).

Energy loss due to submergence is given by

$$E_{bio} = A_{sub}*Gr*(CV)*\eta_c \tag{5}$$

where A_{sub} is the area submerged, Gr is the annual rate of growth or productivity, CV is the energy equivalence factor and η_c is the energy conversion efficiency.

The area submerged is further classified as forest, agricultural lands, gardens, etc. The thermal content of biomass is computed in terms of their primary energy contents. For example, a ton of dry fuelwood with a calorific value of 4400 kcal/kg has a thermal content of 5112 kWh, which is considered equivalent to the same amount of electrical energy. This model is subject to the following constraints:

8.2.1. The hydrological constraints

These operate on a monthly basis and consist mainly of the following continuity equation [9].

$$V_{t+1} = V_t + I_t - S_t - E_t - D_t \tag{6}$$

where V_t is the volume of the reservoir at the beginning of month t, I_t are the inflows to the reservoir, S_t is the seepage loss, E_t is the evaporation loss and D_t is the discharge from the reservoir during the month t. To solve this, several inputs are required:

1. Functional relationship between volume, surface area and water level;
2. Relationship between seepage and volume;
3. Relationship between evaporation and volume;
4. Sequence of monthly inflows into the reservoir;
5. Policy for determining the discharges from the reservoir; and
6. Volume of the reservoir when the simulation begins.

A certain amount of ‘dead’ storage capacity was added to account for sedimentation.

8.2.2. Dependability

The storage capacity (V) of any reservoir is the function of both targeted draft (D) and reliability (R), given by

$$V = f(D,R) \tag{7}$$

It is seen that the required reliability of the targeted draft has a direct relation to effective storage capacity, which has to be provided. For a given draft, particularly the one approaching a mean flow, the required storage is extremely sensitive to reliability. Likewise for a given level of reliability, an increase in the targeted draft would result in large storage. Thus, for a given draft, storage would increase substantially with increased reliability levels. For hydro planning, in the case of generation schemes, a dependability criterion of 90% is normally adopted. Failure for a month in a decade would mean a reliability of 99.2% on a monthly, but 90% dependability on a yearly basis. This is because, failure in any one month is considered to be failure for the whole year.

8.2.3. Constraint on seasonal variation in generation capacity

If no variation is allowed

$$P_{tm} = P_{td}, \tag{8}$$

That is, the hydroelectric generation capacity during monsoon months (P_{tm}) is same as that during the non-monsoon period (P_{td}).

If seasonal variation is allowed, $P_{tm} \geq P_{td}$

If variation of “r” is allowed $P_{tm} \geq r*P_{td}$ (9)

P_{tm} and P_{td} are written in terms of power draft as

$$P_{tm} = k1*D_{tm}/LF_{tm} \text{ and } P_{td} = k1*D_{td}/LF_{td} \tag{10}$$

where D_{tm} and D_{td} are power drafts from reservoir (in Mm^3) and LF_{tm} and LF_{td} average load factors during monsoon and dry months, respectively, in each case. Therefore,

$$D_{tm}/LF_{tm} = D_{td}/LF_{td} \tag{11}$$

$$D_{tm}/LF_{tm} \geq r*D_{td}/LF_{td} \tag{12}$$

We have same load factor for monsoon and dry months (assumed as 0.5),

$$LF_{tm} = LF_{td} = LF \tag{13}$$

Seasonal variation in generation capacity could be written as

$$D_{tm} = D_{td} \tag{14}$$

$$D_{tm} \geq r*D_{td} \tag{15}$$

8.2.4. Constraint on minimum storage

Active storage capacity $Ka \geq Vt$ for $t = 1,2,\ldots 12$ (16)

8.2.5. Operating policy of the reservoir

The feasible operating policy, considering seasonal variation in water inflow, would be:

$\{S1*P_{tm} + S2*P_{td}\}*30*24*LF*$ (amount of water/million units) = Total qty. of water available at site where $S1 = 4$, (monsoon season) and $S2 = 8$, (lean season) and from Eqs. (10) and (13) this constraint reduces to

$$4*D_{tm} + 8*D_{td} = V_{t+1}$$

where $D_{tm} = D_{td}$, if no variation is allowed. $D_{tm} \geq r* D_{td}$ where the value of 'r' ranges from 1, 2…∞, and $V_{t+1} = V_t + I_t - S_t - E_t - D_t$.

With a change in the dam height, the submergence area and storage volume changes. The submergence area and volume computation is discussed later in case studies. The regulation through storage could be shown as follows:

If $V_t + I_t - S_t - E_t - D_t \leq$ storage volume of reservoir (V_s), then

$$D_t = V_t + I_t - S_t - E_t \tag{17}$$

If $V_t + I_t - S_t - E_t - D_t \geq$ storage volume of reservoir (V_s), then

$$D_t + d = V_t + I_t - S_t - E_t \tag{18}$$

where d is the excess quantity available for generation.

8.2.6. Positivity constraints

Decision variables are positive.

$$D_t \geq 0, \text{ for all } t = 1,2\ldots12$$

$$\text{and } V_t \geq 0, \text{ for all } t = 1,2\ldots12$$

$$\text{Therefore, } Ka \geq 0 \tag{19}$$

This design is implemented for the hydroelectric scheme at Magod.

8.3. River discharge

The hydrology of the Bedthi river was analysed daily and weekly using 5 years' daily precipitation data. The average annual yield at Magod is 1125 Mm^3 by the rational method, compared with 1105 Mm^3 by the empirical method. Ninety per cent dependable water yield is estimated as 995 Mm^3. Water yield computed at Magod by the empirical method with 90 years' precipitation data shows that water quantity varies from 0.25 (avg) ± 1.25 (SD) during January to 364 (avg) ± 136 (SD) during July.

8.4. Evaporation, seepage loss and silting capacity

These losses are estimated as 99 Mm^3 per annum for 100 sq km of the region. About 48% of the basin area is plain with partial vegetation cover receiving moderate rainfall. The remaining area is hilly with evergreen vegetation. The silt rate per annum (S) is given by $S = C(A)^{3/4}$ where $C = 4.25$ assumed for the basin with plain and forested tracts. For Magod, the silt rate is found to be 0.83 Mm^3 per year. At this siltation rate, the life of the reservoir at FRL 450–455 m is about 50 years.

8.5. Dam site

The river Bedthi, flowing in a deep and well defined gorge, drains a total area of 4060 sq km. The site proposed is about 0.91 km upstream of the Magod falls, at longitude 74°45′28″E and latitude 14°51′41″N. This site commands a basin of 2084 sq km and has an exposed rocky bed at the flanks on either side. The river bed level here is 373 m and is 36 m wide. At 450, 460 and 480 m contour elevations, the length of the dam would be 392, 436 and 579 m, respectively.

8.6. Dam height and submergence area

A dam at this site submerges areas having biomass like firewood, twigs etc. and bio residues of agricultural and horticultural lands, which is used for domestic, commercial and other purposes. This energy is significant. When the water head is very high and the reservoir profile a deep valley with steep walls at its sides can hydroelectric energy be very competitive compared to bio energy. When the water head is not much and the terrain has a slope less than 25°, then the smaller depths of a reservoir with less submergence area make firewood an attractive option.

In order to find the contours of submergence areas corresponding to certain dam heights, Survey of India's 1:50 000 scale toposheets are used. The area is computed using a planimeter. The volume of water stored for a particular dam height computed by assuming the volume between two consecutive contours to be trapezoidal is

$$V_{12} = (a_1 + a_2)*0.5*h_{12} \tag{20}$$

where V_{12} is the volume between contours 1 and 2, a_1 is the area of spread of contour 1, a_2 is the area of spread of contour 2 and h_{12} is the height difference between contours 1 and 2. The generalized form could be written as,

$$V_{ij} = \sum_{k=i}^{k=j-1} V_{k,k+1} \quad \text{and } i = 1,\ j = i = 1,\ i + 2, \ldots\ldots, \tag{21}$$

The submergence area and corresponding volume computed for different dam heights at Magod are depicted in Fig. 5. This shows that, when the dam height is 67 m, the submergence area is 5.7 sq km and the vol-

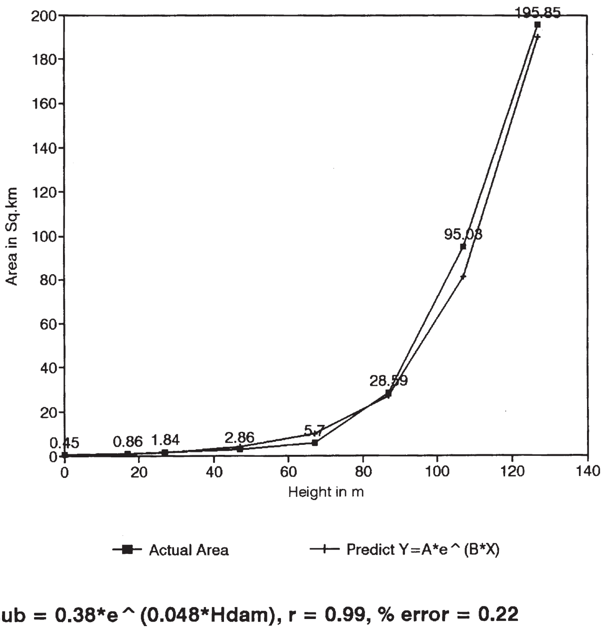

Fig. 5. Dam height and corresponding submergence area.

ume is 106.35 Mm^3. Beyond 87 m, there is a steep increase in submergence area, as is evident from a submergence area of 95.02 sq km for a dam height of 107 m. The relationship between the submergence area and the height of the dam is found to be either powerlaw or exponential ($A_{sub} = 0.38*\hat{e}(0.048*H_{dam})$) with $r = 0.99$, and percentage error 0.45. Similarly, the probable relationship between the volume of water and the height of the dam is exponential ($V_{dam} = 5.03*\hat{e}(0.054*H_{dam})$) with $r = 0.99$ and percentage error 0.22 (Fig. 6).

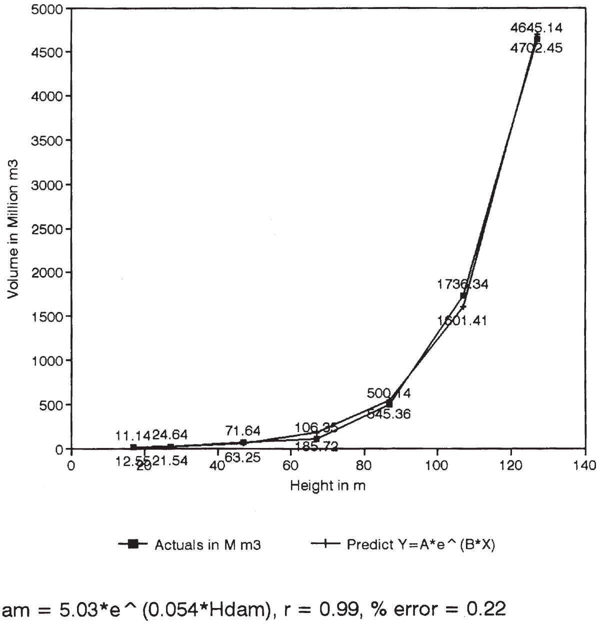

Fig. 6. Dam height and corresponding storage capacity.

8.7. Net energy analysis

We have computed the hydro power equivalent at each site before maximizing the net energy function. Energy from water is computed based on parametric optimization techniques, listed in Table 7. If variation is allowed between P_{tm} and P_{td}, it reduces the storage capacity requirements. By allowing the P_{tm} to P_{td} ratio to be 3, we notice that the submergence area saved is about 69.97%. This results in the reduction of the civil costs of the project. Regression analysis of these variables gives a hyperbolic relationship, given by $En = 733.86 + [(1566.28)/\text{Area}] - [(6024.64)/(\text{area})(\text{area})]$, with $r = 0.99$ and percentage error of 1.04. We harness more hydroelectric energy by drawing the water during the monsoon on a run of river basis and store sufficient quantity to meet the non-monsoon requirements. This saved area would also help in meeting the bio resource requirements of the region. We notice that by allowing variation in the P_{tm} and P_{td} ratio, there is an increase in the electric energy generated. This is because, for smaller heights of the dam, the submergence area is less and therefore evaporation and seepage losses are also less.

8.8. Biomass energy from lands to be submerged

The land use pattern in the area to be submerged for various heights of dam shows that the area under natural forest is the major constituent of the submerged land, consisting of evergreen, semi-evergreen and deciduous forests where the primary production of biomass is estimated to range between 6.5, 13.5, 20 and 27.5 t/ha/year [10]. Areca and coconut residues from gardens are in the range of 3–4.5 t/ha/year.

The reduction in submergence area implies a reduction in the loss of thermal energy. The net energy is computed taking the thermal value of bioresidues available in the region and indicates that with a decrease in dam height, the net energy available increases. As indicated in Table 8 at Magod, the net energy increases from 417 (for a dam of 107 m and biomass productivity of 6.5 t/ha/year) to 803 million units (for a dam of 67 m). The efficiency of a hydro power station is the combined efficiency of turbine, generators etc. It is estimated that this efficiency is around 70%. For this scenario, the net energy function becomes

$$E_{net} = 0.7*Eh - E_{bio}(\text{lost})$$

$$E_{net} = Eh' - E_{bio} \tag{22}$$

To account for only the final amount of electricity, the thermal energy content of source is discounted by the conversion efficiency of a thermal power plant (as 35%). With this

Table 7
Power (in mega watts) and energy (in million kWh)

Site	Height (m)	Sub area (sq km)	Volume (million M^3)	P_1/P_2 ratio	Hydel power P_1 (MW)	P_2 (MW)	Energy (million kWh)
Magod	107	95.03	1736	1	85	85	747
	97	63.23	1135	1	90	90	791
	87	28.59	545	3	158	53	769
	87	28.59	545	4	138	35	769
	87	28.59	545	6	200	33	780
	82	20.77	417	6	204	34	796
	82	20.77	417	4	180	45	791
	82	20.77	417	3	163	54	796
	77	16.27	417	7 (for 2 months)	245	35	771
				4 (for 2 months)	140		
	77	16.27	417	6	210	35	820
	77	16.27	417	4	185	46	811
	77	16.27	417	3	166	55	811
	72	12.74	243	10	250	25	806
				& 8	200		
	70	9.98	186	16	320	20	824
				& 8	160		
	67	5.70	106	32	320	10	824
				& 16	160		

Table 8
Hydro, thermal energy and net energy available from submerged area (million kWh)

	Dam height	Hydro energy *Eh*	*Eh′* 0.7 *Eh*	< ——Bio energy—— > E_{bio} @6.5t/h/year	0.35*E_{bio} E_{bio}'	< ——Net energy—— > Eh-E_{bio}	Eh'-E_{bio}'
Magod	107	747	523	330	115	417	407
	97	761	532	219	77	541	456
	87	780	546	100	35	680	511
	82	796	557	73	26	723	532
	77	811	568	58	20	753	547
	72	816	572	46	16	771	556
	70	824	576	36	13	788	564
	67	824	576	20	7	803	569

$$E_{net} = Eh' - 0.35{*}E_{bio} \text{ (where } Eh' \text{ is } 0.7{*}Eh) \qquad (23)$$

The result of this computation, given in Table 8, shows that a variation in the net energy available ranges from 407 to 569 million units at Magod.

The domestic fuelwood consumption survey of this region reveals that 82 to 90% of the households still depend on fuelwood and agro residues to meet the domestic cooking and water heating requirements. The annual fuelwood energy requirements are estimated to be 312 million units. System efficiency considerations, peak power considerations and socioeconomic considerations all rule out the possibility of electricity entirely substituting fuelwood as a source of domestic energy. Therefore only a fraction of the wood energy is converted into electrical energy, that is equal to the fraction of the purely non-thermal consumption of electric energy in a total wood and electric energy consumption. A dam height of 107 m at Magod submerges about 95.03 sq km, of which 88.53 sq km is under evergreen and semi-evergreen forests, rich in biodiversity. This necessitates eco-friendly options, to reduce the submergence of prime forests.

The model and subsequent quantitative analyses demonstrates that much of the land could be saved from submergence if the hydroelectric power generation capacity is adjusted according to seasonal variations in the river's runoff. The viability of a mixed hydro and biomass generation system is shown in energy terms, which leads to a significant reduction in the total area used for power generation. Apart from this, there is scope to generate hydroelectric energy from streams in a decentralized way.

8.9. Economic analysis

8.9.1. Computation of costs: net loss due to forest submersion

Forests play a role not only in the social and economic wellbeing of the society but also in maintaining the ecological balance. With the submersion of forests, benefits such as (a) fuelwood, (b) timber, (c) grass and other biomass material, (d) forest products such as cane, bamboo, gums, resins, drugs, spices, etc., (e) biodiversity, (f) recreation and (g) environmental benefits, such as soil conservation, recycling of water and the control of humidity, etc., are lost. Direct costs of the submerged area are assessed by considering standing biomass in the area, which is based on species diversity studies carried out in sample plots at Sonda, Kallabe, etc. In this computation, the price of forest land is taken as Rs 111 200 per hectare.

8.10. Loss due to submersion of agriculture and horticulture land

The costs involved in the submersion of agriculture lands, areca nut gardens and coconut plantations were based on the market value of the land in this region. The value of areca nut garden is Rs 890 000 per hectare, while for paddy, it is Rs 99 000 per hectare and coconut plantation is about Rs 218 000 per hectare. The details of villages submerged and the number of households affected are obtained from government agencies like the Village Accountant’s office. The displacement and rehabilitation costs were based on the data from earlier hydroelectric projects.

8.11. Annual charges on capital costs

The capital cost depends on (a) civil construction costs (size and type of dam) and (b) cost of generating unit, which depends on the capacity. The capacity is calculated using a normal load factor of 0.5. The schedule of rates approved by the government recently has been used in computing civil and electrical costs. Annual capital recovery factor (annuity factor) is calculated for the total cost (civil plus electrical plus environmental plus rehabilitation) at 12% interest for 50 years of satisfactory functioning of the power station.

8.12. Operation and maintenance (O and M) charges

Annual O and M charges are taken as 1% of the total cost of the project. The depreciation works out to be 1.80%, taking into account the life of dam as 70 years, surge shafts, penstock, power house equipment, power house building and substation equipment as 50 years, and roads, etc. as 35 years. Hence, annual cost

$$C = \text{Annuity factor*Total cost} + \text{O and M charges} + \text{Depreciation cost}$$

With this annual cost and energy information, we have computed cost per unit of energy (see Table 9). Fig. 7 lists cost per unit (cost per kWh). It shows 40.5% reduction in cost (Rs 1.53 per unit to Rs. 0.92 per unit) for a dam height reduction of 32.75%. If we consider

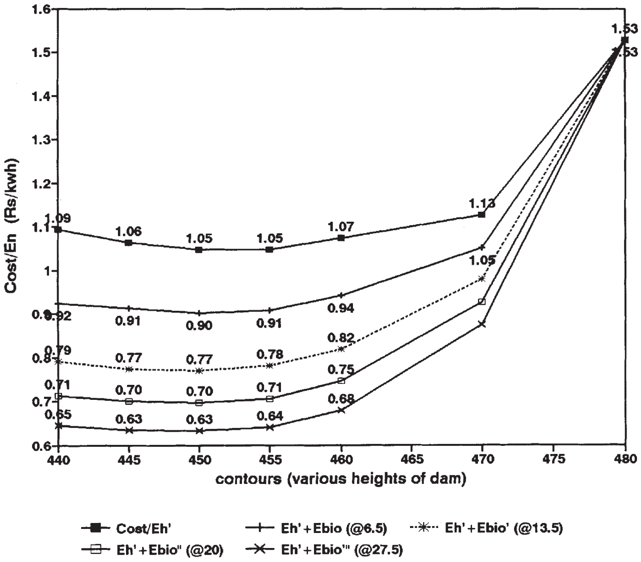

Fig. 7. Cost (Rs per kWh) of energy for various designs.

Table 9
Cost per unit (kWh) of electricity (considering biomass productivity as 6.5 t/ha/year)

		Net energy		< ———Cost per unit (kWh) of electricity——— >			
		$Eh + E_{bio}$	$Eh' + 0.35*Eb$	Cost/Eh	Cost/Eh'	$Eh + E_{bio}$	$Eh' + 0.35*E_{bio}$
Magod	107	746.66	522.66	1.07	1.53	1.07	1.53
	97	870.90	571.01	0.79	1.13	0.69	1.05
	87	999.20	622.74	0.75	1.07	0.59	0.94
	82	1041.30	643.18	0.73	1.05	0.56	0.91
	77	1070.60	658.50	0.73	1.05	0.56	0.90
	72	1087.90	666.53	0.75	1.06	0.56	0.91
	67	1126.88	688.44	0.77	1.09	0.56	0.92

electricity from water resources only, then cost reduction is from Rs 1.53 per unit to Rs 1.09 per unit.

9. Conclusions

The potential assessment of streams in the Bedthi and Aghnashini river catchment shows that most of the streams are seasonal and cater for the needs of local people in a decentralized way during the season. This ensures a continuous power supply during the heavy monsoon, which otherwise gets disrupted due to various problems. This study explores the possibility of harnessing hydro potential 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 years. The hydro energy potentials of streams in the Bedthi and Aghnashini river catchments are estimated to be about 720 and 510 million kWh, respectively.

The net energy analysis explains the upper limit on the height of a dam and, therefore, the area of the reservoir for the project to yield a positive net energy. Also, it is noticed that savings in land submergence could be achieved by adjusting hydroelectric generation capacity according to seasonal variation in the river runoff. The parametric optimization technique is used to compute energy from a hydro source at Magod. By allowing a seasonal generation ratio of 3, the submergence area saved is about 69.97%, and we notice the subsequent increase in electric energy generated. This is mainly due to less evaporation and seepage loss due to a reduced submergence area for smaller dam heights.

Net energy analyses carried out by incorporating the bioenergy lost in submergence at Magod show a gain of 63.9% for a reduction of 37.3% in dam height. Apart from the distinct reduction in submergence area, the overall reliability of a hydro and thermal combined system is much higher than that of pure hydro systems (which are very sensitive to fluctuations in rainfall). The fuelwood requirement in the region is about 312 million units (million kWh) for domestic purposes. 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 bio resource potential of 319 million units, which can cater for 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 (Rs 1.53 per unit to Rs 0.92 per unit) for a dam height reduction of 32.75%.

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Appendix A

Classification of hydro power plants

Table 10
Systems based on power and head: mini, micro and small hydro power plants

		Head (metres)		
	Power (kw)	Low head	Medium	High head
Micro	up to 50	< 15	15–50	> 50
Mini	50–500	< 20	20–100	> 100
Small	500–5000	< 25	25–130	> 130

The upper and lower head and output limits adopted for any classification is an indicative only.

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