BIOENERGY STATUS OF SHARAVATHI RIVER BASIN, WESTERN GHATS, INDIA

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ABSTRACT

Most of the developing countries including India depend heavily on bioenergy and it accounts for about 15% of the global energy usage. Its role in meeting a region's requirement has increased the interest of assessing the status of biomass availability in a region. The present work deals with the bioenergy status in the Linganamakki reservoir catchment of the Sharavathi river basin, Western Ghats, India, by assessing the energy supply and sector wise energy consumption. The study reveals that majority of the households (92.17%) depend on fuelwood for their domestic energy needs with the per capita fuelwood consumption of 1.2 tonnes/year, which is higher than the national average (0.7 tonnes/year). This higher dependence on fuelwood has contributed to the degradation of forests, resulting in scarcity of bioresources necessitating exploration of viable energy alternatives to meet the growing energy demand.

Keywords: Bioenergy, Biostatus, Energy alternatives, Biogas, Sustainable Energy.

1.INTRODUCTION

Energy is considered as the prime mover of a region's development. In India, more than 70% of the total population inhabits rural areas and 85–90% of energy requirement is being met by bioresources. In the context of energy crisis due to dwindling of fossil fuel based energy resources, the importance of biomass as a renewable energy resource has increased in recent years. Although biomass energy is

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predominantly used in rural areas, it also provides an important fuel source for the urban poor, and many rural, small and medium scale industries. Field investigations reveal that most of the rural population still depends on the traditional devices (which are energy inefficient) for cooking and water heating, etc. leading to excess consumption of local resources. Lack of information about the resources and technologies may be cited as the reason for this situation.

Bioresources are diverse solid carbonaceous material ranging from fuelwood collected from farmlands and natural woodland, to plantation crops grown specifically for energy purposes, agricultural and forestry residues, food and timber processing residues, animal residues and aquatic flora. The energy released from the reaction of these materials with oxygen is known as bioenergy and it is being used in various ways to meet daily energy needs of the society. Bioenergy is the most developed renewable energy, providing 38% of the primary energy needs of developing countries. In the developing world as a whole, about 2 billion people rely solely on fuelwood as their energy source for water heating and cooking. In order to achieve sustainable, self-reliant and equitable development of a region, it is imperative to focus on efficient production and use of bioenergy to meet both traditional and modern fuel requirements.

The rural energy scenario in India is dominated by the domestic sector, which accounts for 75% of the total energy consumed. The fuel consumption pattern of the domestic sector in rural areas is characterized by higher dependence on bioresource-based fuels such as fuelwood, agricultural residues, etc. Cooking and water heating (for bathing and washing) are the prime end-uses in domestic sector accounting for over 90% of the energy. Rural population still depends on the traditional devices for cooking and water heating, etc., which are energy inefficient leading to excess consumption of local resources. This is mainly due to the lack of knowledge of energy efficient devices and renewable energy technologies. According to the recent National Sample Survey (NSS) data, about 36.5% of fuel needs in urban and 17.2% fuel needs in rural area is met by sources like kerosene and electricity. All other cooking is done either with fuelwood or dung cakes. This reveals the higher dependence on bioresource to meet the energy requirement that is mainly due to availability of bio-fuels at zero private cost and also non-availability of other sources of energy (high costs and unreliable supply network).

The estimate done at regional level for Karnataka (a federal State in India) shows that 8.5 million tonnes of fuelwood is required annually for cooking purpose in Karnataka. Inclusion of additional domestic demands such as water heating, space heating, etc., pushes it to 11.2 million tonnes annually. The demand for fuelwood is continuously rising along with increase in population. The State has only 16.9% of the area under forests (38,724 km^2 of the total area of 191,791 km^2).

The burgeoning population coupled with unplanned developmental activities based on ad-hoc decisions has led to bioresource scarcity in many parts of Karnataka. Present fossil fuel potential is unable to meet the growing demands of the society. There is a need to look for viable alternatives to meet the scarcity. Thus, there is a requirement for interventions particularly in rural development and in general, the energy system to boost the energy potential at disaggregated levels to balance demand

and availability. This necessitates the understanding of the present energy consumption pattern and exploring locally available alternative energy sources in order to ensure resource sustainability.

Alternatives like biogas technology has made inroads in rural economy in some districts like Uttara Kannada,Udupi, Shimoga, etc. in Karnataka State (with higher literacy among women) during the last two decades due to economic viability, ecological soundness, technical feasibility and social acceptance. Biogas from biomass and animal wastes is an excellent technology that provides an alternate source of fuel in rural areas with an output of both energy and manure by using locally available resources like animal dung and other organic material.India is a pioneer in the field of developing technology for biogas production from animal dung (Srinivaran, 1979). Animal dung is a potentially large biomass resource and dried dung has the same energy content as wood. When burned for heat, the efficiency is only about 10%. About 150 million tonnes of cow dung (dry) is used for fuel each year across the globe, 40% of which is in India (UNEP, 1980). Biogas is produced by biological decomposition of organic material in the absence of air. The efficiency of conversion of animal residues could be raised to 60% by digesting anaerobically (to produce biogas). Biogas production will also resolve the conflict between energy recovery and nutrient utilisation as the effluent from the digester could be returned to the fields.

For 2002–03, a target of setting up of 0.12 million family type biogas plants had been allocated to States and agencies. About 70,440 plants have been completed during the period April to December 2002, which is almost 117% over the target of 60,000 plants planned for the corresponding period (MNES, 2003).

Current study was carried out in the Linganamakki reservoir catchment of Sharavathi river basin, Western Ghats, India to assess the impacts due to developmental work (in the form of hydroelectric power stations with reservoir) on local energy resources and demand. This region is considered to be one of the biodiversity hotspots as it harbours rich flora and fauna. The people residing in this area are largely dependent on these forests for daily energy needs (fuelwood) and sustenance. It is observed that the boundary of the energy flow extends beyond the sub-basin limit of the Sharavathi River. Hence a river basin-hydrological unit is considered for this investigation as energy movement is related to geographical features and shows similar trends in relatively homogenous features.

Karnataka State mainly depends on hydroelectricity (67%) of which Sharavathi river basin's share is about 48%. It is one of the west flowing rivers of India, which traverses over a length of 132 km through undulating terrain in the Western Ghats with rich biodiversity and joins the Arabian Sea. The study area is situated at latitude 74°67'11" to 75°30'63" east and longitude 14°7'27" to 13°77'08" north with an area of 1992 sq. km. This river is extensively utilized for hydroelectric power generation (1450 MW). The Karnataka Power Transmission Corporation Limited (KPTCL) has constructed a dam at Linganamakki towards meeting the electricity requirement of the State.

The Linganamakki reservoir is about 105 km west of the district headquarter, Shimoga. Figure 1 provides the location of the study area while; Figure 2 is the remote sensing composite image that was used to assess the bioresource availability in various

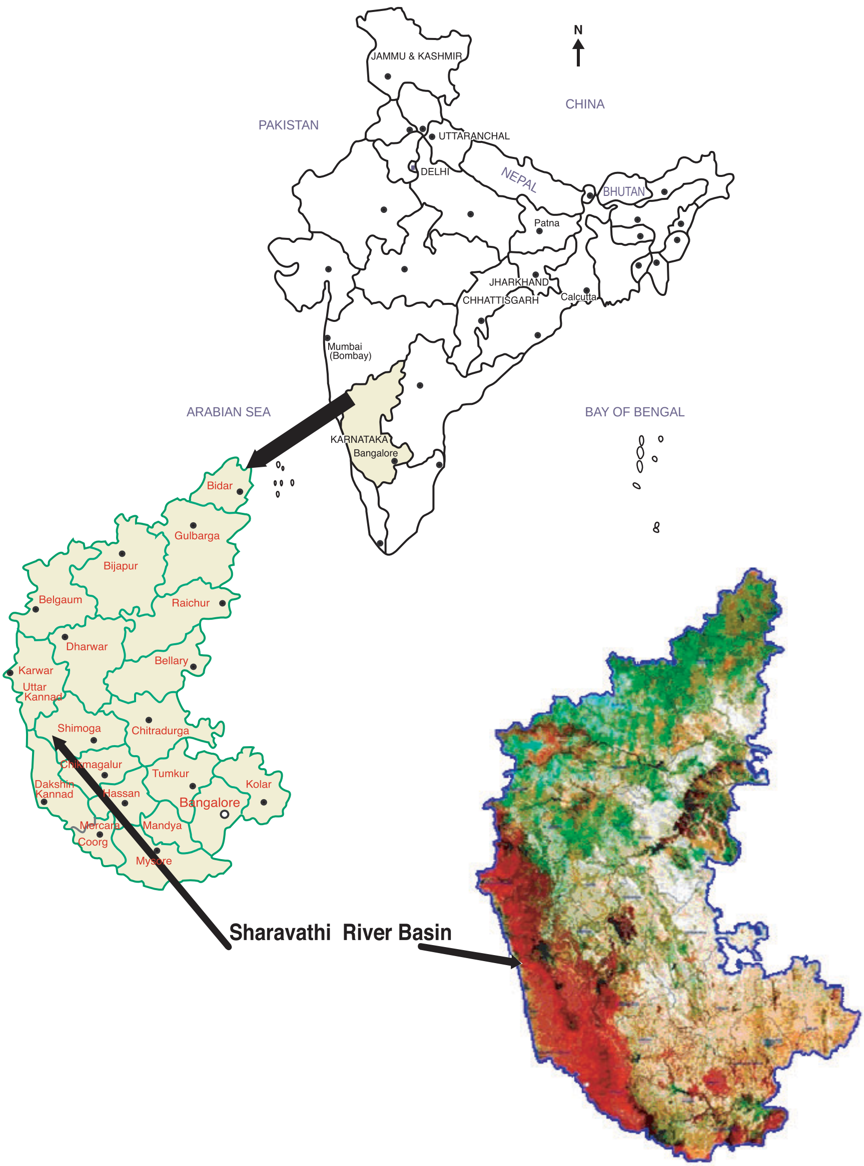


Figure1: Location of the study area.

land use categories. The mountainous terrain of Western Ghats binds the western part of the study area, which has rich vegetation cover of evergreen to semi-evergreen type. The vegetation richness gradually recedes towards east. The hills slope towards east and transition between Maidan and Malnad can be seen on eastern part of the study area. It is further divided in to sub-basins based on major tributaries and associated streams as given in Figure 3.

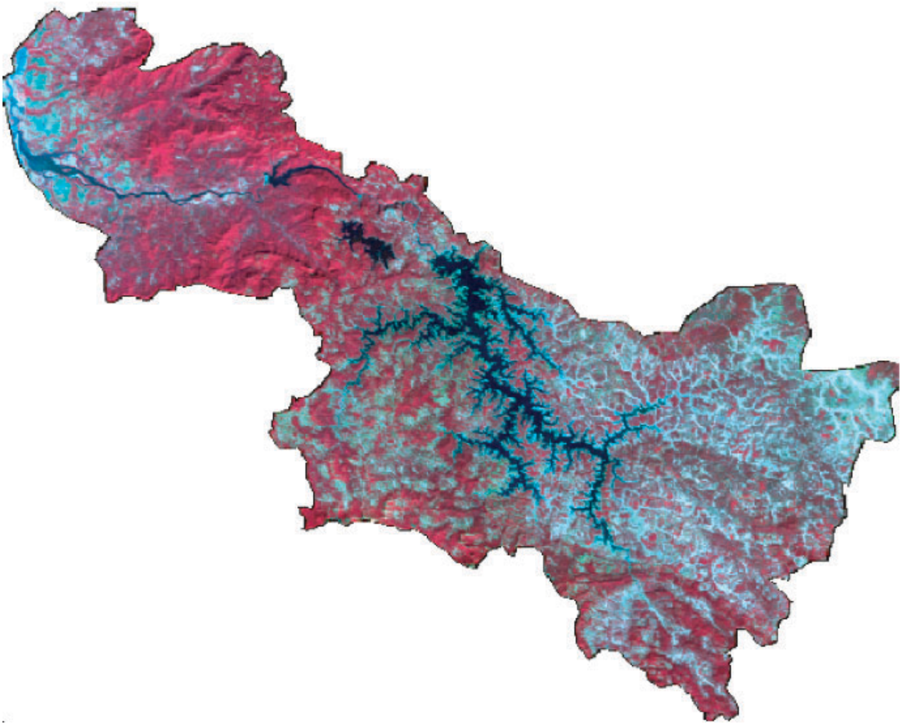
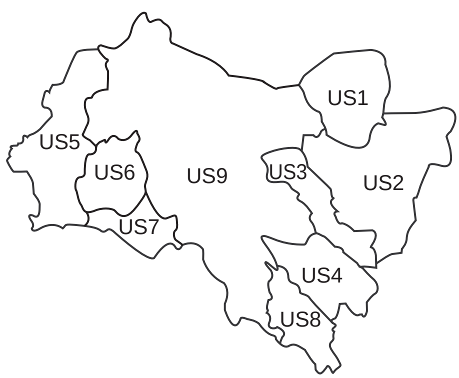


Figure 2: Remote sensing composite image of the study area.



US1	Nandiholé	US2	Haridravathiholé	US3	Mavinaholé
US4	Sharavathi	US5	Yenneholé	US6	Hurliholé
US7	Nagodiholé	US8	Hilkunjiholé	US9	Linganmakki (Central Zone)

Figure 3: Sub-basins in the study area.

Assessment of the energy consumption pattern and bioresources availability was done in order to quantify the energy demand and to understand the present status of energy supply and prospects for alternate policies and technologies along with management strategies to ensure the sustainability of the ecosystem. The Ministry of Environment and Forests, Government of India through the forest departments in each State has implemented the JFPM (Joint Forest Participatory Management) programme through a participatory approach involving village communities and voluntary agencies in the conservation and regeneration of forests. The performance of this programme in the river basin has been explored to assess the efficacy in resource management. Presently under JFPM, about 23 Village Forest Committees (VFCs) are active.

The National Commission on Agriculture (NAC) in 1976 projected the fuelwood demand up to the year 2000 (Kumar, 1999). The net per capita fuelwood consumption was estimated at about 194 kg/year. The demand projections estimated on that basis for fuelwood was 157.5 million tonnes in 2000. The Commission did not project an appreciable shift away from non-commercial fuels.

Comparative analysis of village level domestic energy consumption patterns across coastal, interior, hilly and plain zones considering regional and seasonal variations was done for Uttara Kannada District in 1999. Average consumption (kg/capita/day) of fuel wood for cooking ranges from 2.01 ± 1.49 (coastal) to 2.32 ± 2.09 (hilly). Season wise cooking fuel wood requirement for coast and hilly zones, ranges from 1.98 and 2.22 (summer) to 2.11 and 2.51 (monsoon) respectively, while for water heating (for bathing and washing), it ranges from 1.17 ± 0.02 (coast) to 1.63 ± 0.05 (hilly). Examination of present role of biomass in the energy supply of Uttara Kannada district, Karnataka and the potential for future biomass provision and scope for conversion to both modern and traditional fuels reveals that fuel wood was mainly used for cooking, and horticultural residues from coconut and areca nut trees were used for water heating purposes. Most of the households in this region still use traditional stoves whose efficiency is less than 10%. Energy from various crop residues was calculated: paddy husk-170.12 million kWh, bagasse-136.3 million kWh, groundnut-11.64 million kWh and maize-1.66 million kWh. The total residues available for the district were calculated to be 42020.37 tonnes. The total energy available from horticultural residues is: areca-540.58 million kWh, coconut-247.04 million kWh and cashew–38.365 million kWh. The total biogas available was calculated to be 46.29 million m^3, which could meet 30% of the population's energy demand. The fodder requirement was estimated to be 1.09 million tonnes of which 0.21million tonnes could be met by agro-residues. The improved cook stoves (ASTRA stoves-designed at ASTRA, Indian Institute of Science) were distributed under an eco-development programme, which was done through local people's active participation and after consultations with the villagers and local NGOs (Non-Governmental Organizations). These stoves are characterized by complete fuel combustion with as little excess air as practicable to generate the highest temperature of flue gases. The efficiencies of these stoves are in the range of 32–41%.The study also reveals that grazing in forests as well as removal of fuelwood (for domestic and small scale industries) has affected the sustainability of the forests, as there is large-scale degradation in many localities (Ramachandra et al, 2000).

Centre for Sustainable Technologies (formerly known as ASTRA), Indian Institute of Science conducted a detailed survey in six villages in a dry arid zone that revealed: (a) fuelwood is a dominant energy source (81.6%) used mainly for household activities, (b) cooking is a major activity consuming human and fuelwood energy and efficiency of improved stoves are in the range of 5.08%, (c) human energy in h/day/household (especially women and children) was inefficiently used in fuelwood gathering (2.6), cooking (3.68), carrying food to farms (1.82), fetching water (1.53), taking cattle for grazing (5.54) etc., (d) kerosene consumption for lighting is about 4.3l% non-electrified house (78% of the houses being non-electrified) and (e) industrial consumption is very small. Essential factors determining biomass availability for energy are: (i) The future demand for food, determined by the population growth and the future diet; (ii) The type of food production systems that can be adopted world-wide over the next 50 years; (iii) Productivity of forest and energy crops; (iv) The (increased) use of bio-materials; (v) Availability of degraded land; (vi) Competing land use types, e.g. surplus agricultural land used for reforestation. The focus has been put on the factors that influence the potential biomass availability for energy purposes.

Six biomass resource categories for energy are (i) energy crops on surplus cropland, (ii) energy crops on degraded land, (iii) agricultural residues, (iv) forest residues, (v) animal manure and (vi) organic wastes. The amount of re-circulating biomass is the key variable for controlling nutrient availability within an ecosystem. In this regard, recycling of biomass, rotation of crops, and biomass-producing strips inter-cultured with crop areas maintain the nutrition balance in agricultural lands. Part of the biomass is locally consumed in providing fodder to the draught animals. It can be used as a layer to suppress evaporation and as organic input for crop production, satisfying part of the nutrient requirements enhancing soil fertility and improving its moisture holding and permeability characteristics (Datye, 1997).

Even though forests cater most of the daily energy needs in rural areas, there is a need to focus on viable energy alternatives to cater to the growing demand of the burgeoning population. In this context, biogas generators lessen the dependence on forest and increases green areas leading to improved environment. More than 2 million biogas plants have been built in India so far. With a potential market for 30 plants attached to households with 3 cattle or more, the social and environmental advantages of biogas are just beginning to be explored. In rural areas, where there is generally no electricity supply, the introduction of biogas has given women a sense of self-worth and time to engage in more activities outside the home (Rene and Gunnar, 1997). Important sociological issues that have prevented widespread adoption of Biogas generators in India (during the evolution of biogas) are scarcity of animal residues, asphyxiation, fire explosion, kitchen fire, digester bursting or cracking and hazardous developments with respect to human safety (Goswami and Sutar, 1993).

Stall-feeding instead of field grazing is one of the best ways to circumvent the scarcity of animal residues and it facilitates increased production of biogas. Also, it would aid the regeneration of forests as the damages to saplings are minimised. However, stall-feeding is a labour-intensive activity demanding high labour inputs during the growing season. Cutting and carrying grass and carrying water to the cattle absorb 60–75% of the total labour. Slurry of biogas plant serves as manure and supply humus to soils, thereby helps in soil conditioning (John, 1986).

However, certain barriers hinder the overall potential of community biogas plants for cooking. Compared to biogas, fuel wood is available at zero cash cost and the cost of a stove is still high and acts as a deterrent, especially for the poor. Scarcity of large funds hinders the installation process of biogas plants. NGOs are suffering with improper incentive facilities for construction and maintenance, and also with unavailability of technology packages and adequate demonstration units. No organization at village level is willing to take leadership and accept responsibility of biogas plants. Inadequate funding and scarcity of skilled personnel for construction and maintenance affect the full potential use of biogas plants. Maintenance of biogas plants in some areas is affected by scarcity of water. Women and children play a dominant role in most of the household activities (like gathering of fuelwood, cooking etc.), but lack of representation of women in decision-making has also contributed to the problem.

The barriers for improved cooking technologies could be grouped as financial, technical and institutional from both supply and demand perspective. The improved stove cost varies with the design and is expensive compared to the traditional stoves. The government provides subsidy for improved stoves, which the households claim after the installation. Some households still consider the cost as high due to lack of knowledge of certain direct and indirect benefits, and also availability of fuel wood, dung cakes and crop residues with no cash expenditure. Inaccessibility of the improved stove accessories along with the scarcity of the trained builders and service facilities in rural areas hinder the diffusion of devices. The distance from the nearest urban centre and availability of transportation facilities also plays a dominant role in adopting the alternate energy technologies (Ravindranath and Hall, 1995).

The entire study area falls under two taluks namely, Sagar and Hosanagara of Shimoga District. Talukwise bioenergy available in the study area from agricultural residues, forests, horticultural residues, plantation and livestock is tabulated in Table 1.This shows that despite good resource potential in the region, growing demand for fuelwood would threaten the sustainability of the resources. In order to understand the impacts at local scale, the entire upper river basin is divided into eight sub-basins based on the major tributaries and their respective watershed areas. The central part does not fall under any of the major tributaries and was considered separately (central zone). The western part of the river basin has three sub-basins, southern part has two sub-basins and the eastern part has three sub-basins.

Bioresource availability and energy demand assessments were done through primary and secondary data collections. The primary data collection mainly aimed at quantifying the energy needs, identifying the technological options, selection of the best options and integrating the optimal mix of technologies. Secondary data collected from government departments at district and taluk head quarters included villagewise demography and occupational and infrastructural facilities data, land holding particulars of the individual households (agriculture, horticulture, landless, etc.), household list of each village, village level data on livestock population, landuse data, cropping pattern, productivity and the daily rainfall data for the last 50 years.

Table 1: Talukwise bioenergy availability in the study area

Taluk	Total area (ha)	Total Population	Total bioenergy availability (million kcal)					Total Availability (million kcal)	Demand (million kcal)	Status
			Agricultural Residues	Horticultural Residues	Forests	Plantation	Livestock			
Sagar	194009	200211	36367.10	2404076	1807114.0	41607.49	45072.44	4334237.03	816860.9	5.30
Hosanagara	142279	115019	29818.66	1387760	956524.2	15185.86	59453.78	2448742.50	469277.5	5.22

Table 2: Category wise adult equivalents (AE) for computation of PCFC

Category	AE
Men (between 18–59 years)	1.00
Women (between 18–59 years)	0.80
Men (>59 years)	0.80
Women (>59 years)	0.80
Boys (between 6–18 years)	0.50
Girls (between 6–18 years)	0.50
Kids (between 1–5 years)	0.35
Child (1 year)	0.25

In this regard, questionnaire based stratified random sampling of households was done in a cluster of selected villages to collect the data of energy consumption pattern, resources available, and social, economical and cultural aspects. Forty-two villages were selected which are distributed over the entire study area and based on factors such as per capita forest area, per capita agricultural area, etc., which have a role in the energy consumption pattern in a village.

Land holding by a family is considered as the primary criterion for selection of households for energy survey. Households were selected covering all communities from all land holding (small/medium/large) and land less categories. Totally 447 households in 42 villages were covered, which comprises households of 90 landless labourers. Affordability to advanced technologies is determined by the household income and agriculture is the main income source in the rural area. The social and cultural aspects of the households lead to their own fuel preferences. Thus, community-wise variation in the fuel type and quantity in use can be expected.

Representation of energy consumption data in terms of per capita consumption and standard adult equivalents are useful to visualize the consumption pattern and for easier comparison. Hence the analysis was done through the computation of per capita fuel consumption (PCFC) and is given by 'eqn (1)'.

$$PCFC = FC/P \qquad (1)$$

Where, FC (fuel consumed in kg/day, P = number of adult equivalents.

The adult equivalents for computation of PCFC are listed in Table 2, depending on the age and sex. The total demand for a sub-basin was computed based on the total population and the annual per capita fuelwood requirement.

Quantification of the source-wise bioresources potential (sub-basin wise) was done through land cover and land use analysis using remote sensing data-IRS 1C MSS (Multi Spectral Sensor) data of 1999 and 2003. The land cover analysis shows that 70% of river basin is under vegetation indicating the predominance of bioresources. The bioresource availability under each category was obtained by multiplying the spatial extent of each land use type with the annual productivity. The annual

Table 3: Demographic features of the study area

Sub-basin	Total area (sq. km)	Population density (persons/sq. km)
Yenneholé	189.00	35.87
Nagodiholé	65.17	48.41
Hilkunjiholé	85.08	72.87
\Hurliholé	97.88	76.63
Sharavathi	119.40	94.19
Central zone	540.55	100.48
Nandiholé	143.60	101.27
Mavinaholé	95.08	106.84
Haridravathiholé	278.90	112.49

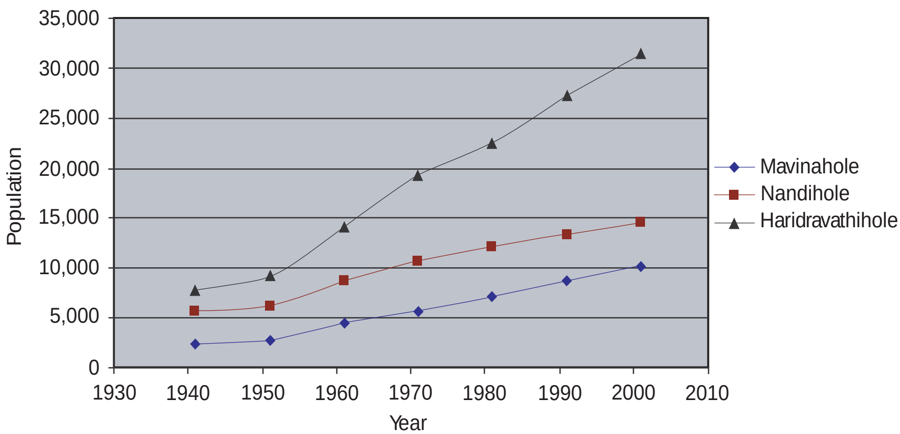


Figure 4: Population trend for the eastern clusters.

availability is based on aggregation of biomass productivity for each type of forest patches. In the present case, the productivity of evergreen to semi-evergreen forests was considered as 3.6–6.5 tonnes/ha/year. The deciduous forests have biomass productivity of 3.9–13.5 tonnes/ha/year. The homogenous plantations were considered as 3.6–6.5 tonnes/ha/year in terms of annual biomass productivity.

2. RESULTS AND DISCUSSIONS

2.1. Demography

The population density computed for each sub-basin is listed in Table 3. Yenneholé sub-basin, which is a part of Sharavathi Wildlife Sanctuary, has low population density. Among all sub-basins, Haridravathiholé sub-basin on the eastern part has high population density (112.49 persons/sq. km). Trends in population change over six decades were analysed for eastern, central and western sub-basins and is depicted in Figures 4, 5 and 6 respectively. In the eastern part of the study area, apart from

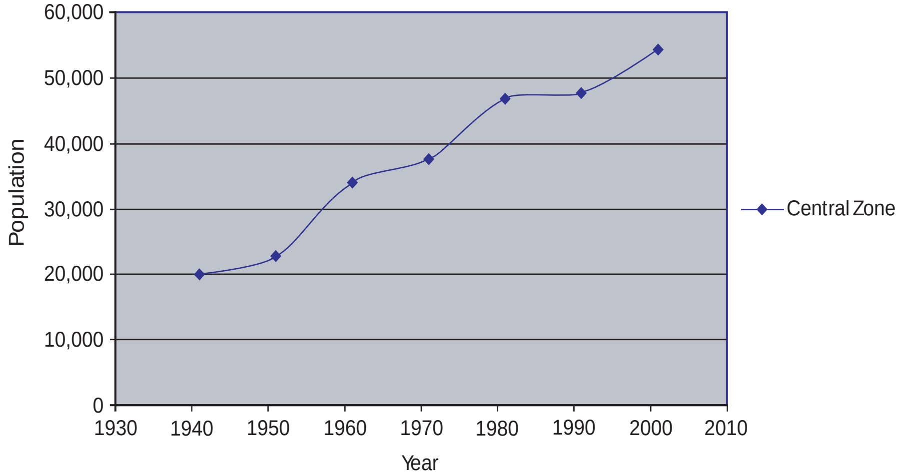


Figure 5: Population trend for the Central zone.

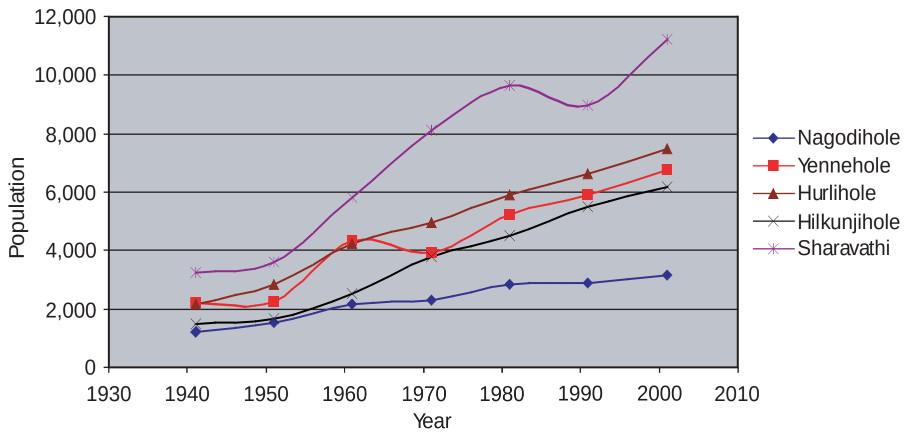


Figure 6: Population trends for the western and southern clusters.

Haridravathiholé sub-basin, Nandiholé and Mavinaholé sub-basins have low rates of population increase. The Sharavathi sub-basin and central zone recorded rapid increase compared to the neighbouring Hilkunjiholé sub-basin. Similarly, population increase is comparatively higher in Hurliholé and Yenneholé (western part) than the Nagodiholé sub-basin.

2.2. Energy Scenario

From Table 4, it is evident that the majority of the households (92.17%) still depend on fuelwood for their cooking energy needs followed by biogas plants (10.06%) and LPG (3.80%). This higher dependence on fuelwood is due to the availability of the

Table 4: Individual share of energy sources in cooking

Energy Source	Number of Households	% Households
Fuelwood	412	92.17
Biogas	45	10.06
LPG	17	3.80

forest resources in the immediate vicinity at zero cost. Two types of fuelwood collection are observed in the region namely, daily collection and seasonal collection. The daily fuelwood collection is the task performed by women who normally spend about 1–5 hours to collect dry and fallen trees from forest areas during non-rainy seasons. The seasonal fuelwood collection is usually performed by men (from nearby households in a group) during summer for usage in monsoon. It involves mainly lopping of trees and some times it is more harmful to the forests as full tree is removed. It was seen that the fuelwood extraction is not uniform over the entire forest patch. The forest areas nearer to human settlements tend to be more deteriorated. Also, normally people cut tree branches or trees, as collecting dead and fallen tree parts are a tedious and time-consuming task. Less dependence on LPG may be due to the lack in availability of resources, infrastructure and higher costs.

The study shows that there is enormous potential for the biogas technology over the study area to replace the usage of fuelwood in domestic energy for cooking. Biogas has a higher heating value than producer gas and coal gas, which implies increased services. As a cooking fuel, it is cheap and extremely convenient. Based on the effective heat produced, a 2m^3 biogas plants could replace, in a month, fuel equivalent of 26 kg of LPGor 37 litres of kerosene or 88 kg of charcoal or 210 kg of fuelwood or 740 kg of animal dung cake. It is a clean fuel without any health hazards or offensive odour and burns with soot less, clean bluish flame thereby making cleaning of cooking utensils easier. Biogas technology has enhanced energy supply decentralization, thus enabling rural areas to meet their energy requirements especially when the commercial fuels are inaccessible. In terms of cost, biogas is cheaper than conventional biomass fuels (dung cakes, fuelwood, crop wastes, etc.) as well as LPG, and is only fractionally more expensive than kerosene. Biogas systems have attracted considerable attention for the potential of waste recycling, pollution control and improvement of sanitary conditions, in addition to providing fuel and manure free of pathogens.

All surveyed houses use twigs and horticultural residues (coconut wastes, etc.) for water heating. In Sagar taluk alone, out of 230 sampled houses, 141 areca land owners use green manure for the plantations. Green leaves required for this purpose, are obtained from the forestland. Each areca plantation owner is permitted by the government to use forests (in the ratio 1:9) for collection of leaves. Farmers lop trees in one-third of the allocated forest area and use green leaves for mulching, while twigs and branches are used for energy production. This method of collection results in canopy opening and degradation of forest patches. This necessitates the exploration of viable energy alternatives to conserve forests while meeting the growing energy demand.

Cooking and water heating are the major domestic end-uses of wood energy. Space heating during winter is met either along with water heating or in paddy fields while

Table 5: Fuelwood consumption among landholding category for cooking and water heating

Type of activity	Season	kg/person/day
Cooking	All	1.82
Water heating	Summer	1.41
	Winter	1.43
	Monsoon	1.56

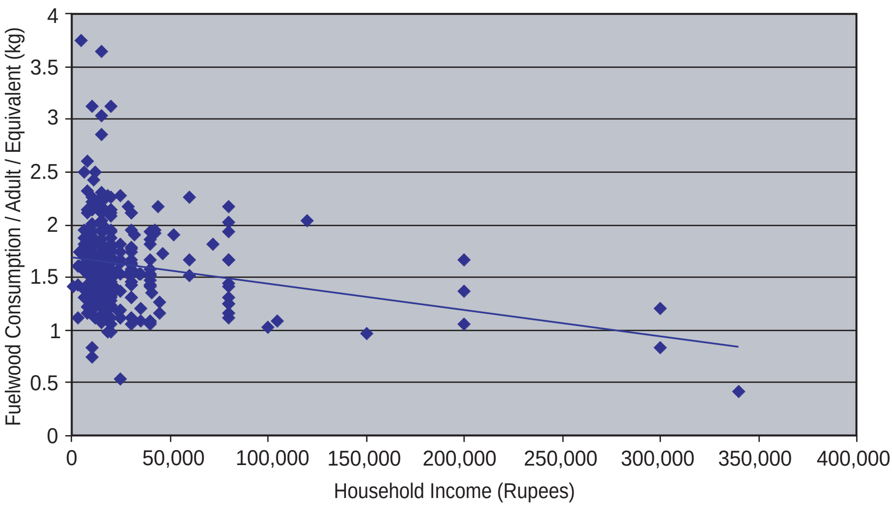


Figure 7: Variation in Fuelwood Consumption for cooking with respect to Household Income.

guarding the crops from wild animals. Quantification of fuelwood requirement specifically for this activity is difficult. The per capita fuelwood consumption for cooking and water heating among landholding category is given in Table 5. Seasonal variation can be clearly seen for water heating as the region experiences extremes in temperature throughout the year. There is no significant variation in cooking fuelwood consumption. Average annual fuelwood consumption by an individual including all activities amounts to 1.2 tonnes. This value is double the national average of 0.7 tonnes/capita/year (Ramchandra et al., 2000a; Sinha et al, 1997). A similar trend of fuelwood consumption was observed in the neighbouring Uttara Kannada district, which showed a yearly per capita fuelwood consumption of 1.44 tonnes (Ramachandra et al, 2000b).

Analyses of fuelwood requirement with respect to income show a linear declining trend as shown in Figure 7. The low-income groups depend on fuelwood as a source of cooking energy. Increase in income promotes the people to afford alternative energy sources like biogas, etc. This transition in the energy ladder has considerably reduced the dependence on fuelwood. The household survey shows that out of 43 biogas

Table 6: Fuelwood consumption among landless category for cooking and water heating

Season	Cooking (kg/person/day)	Water heating (kg/person/day)
Summer	1.62	1.29
Winter	1.88	1.33
Monsoon	1.90	1.52
Average	1.80	1.38

Table 7: Details of the small-scale industries of the region

Industry type	Number of Industries	%Share of wood	Average employment
Agriculture based	21	18.75	5.00
Brick making	5	4.46	—
Food processing	11	9.82	6.14
Wood based	72	64.29	2.78
Miscellaneous	3	2.68	—

owners in the sampled households, 33 households have an annual income of Rs. 30,000. Further, out of the 17 LPG owning households, 16 households have an annual income above Rs. 30,000. However, most of the households in this region belong to low-income category and cannot afford LPG, etc.; there is a scope for energy interventions in the form of improved energy-efficient fuelwood cook stoves or biogas with appropriate financial incentives, service back up, etc.

Due to the changes in socio-cultural practices, livelihood aspects and accessibility to resources, the energy consumption pattern in landless category shown in Table 6, seems to vary from that of landholding category. This category is solely dependent on fuelwood for cooking and water heating activities. Based on this, the annual consumption of fuelwood works out to be 1.16 tonnes/capita. Seasonal variation is seen in fuelwood consumption for cooking as well as water heating. During field survey, it was observed that all households depend on traditional devices for cooking, which are energy inefficient. Use of biogas, LPG and kerosene is absent for cooking.

To assess energy in industry sector, sample survey was conducted for 32 industries out of 112 industries, which depend on biomass. Totally about 112 natural resource based industries were surveyed for analysing the composition and employment abilities of the small-scale industries of the region and results are given in Table 7. These industries being situated in the sub-urban areas of the region, serve as the source of employment to many local people. Wood based industries such as carpentry, manufacture of cane products, etc., constitute 64.29% of the total due to the cheap and easily available wood in the region. This is followed by agriculture-based industries like rice and flourmills with 18.75%.

Sub-basin wise bioenergy status was computed to evolve specific management strategies based on the local conditions, which is given in Table 8. This shows that the

Table 8: Sub-basin wise annual fuelwood availability and demand

Sub-basin	Availability (tonne/year)	Demand (tonne/year)	% Utilization
Central zone	213484.86	65175.6	30.53
Yenneholé	112386.10	8136.0	7.24
Hurliholé	50281.10	9001.2	17.90
Nagodiholé	36978.70	3786.0	10.24
Hilkunjiholé	13788.70	7440.0	53.96
Sharavathi	33564.50	13496.0	40.21
Mavinaholé	34886.90	12189.6	34.94
Haridravathiholé	77481.70	37645.2	48.59
Nandiholé	48416.00	17923.2	37.02

Table 9: Biomass availability from areca residues

Sub-basin	Areca (ha)	Production (tonnes)	Leaves (tonnes)	Inflorescence (tonnes)	Nuts and Husk (tonnes)	Leaf sheath (tonnes)
Mavinaholé	146.48	183.10	1799.47	1384.21	545.77	593.23
Haridravathiholé	282.98	353.72	3476.38	2674.13	1054.37	1146.06
Hilkunjiholé	64.23	80.28	789.02	606.94	239.31	260.11
Hurliholé	260.24	325.30	3197.05	2459.27	969.65	1053.97
Nagodiholé	142.66	178.32	1752.55	1348.11	531.54	577.76
Nandiholé	341.81	427.26	4199.13	3230.10	1273.58	1384.32
Sharavathi	220.97	276.21	2714.66	2088.20	823.34	894.94
Yenneholé	180.39	225.49	2216.08	1704.68	672.13	730.58
Central zone	1160.50	1450.61	14256.59	10966.61	4323.98	4699.97
Total	2800.20	3500.30	34400.92	26462.25	10433.69	11340.96

eastern and southern sub-basins have percentage utilisation greater than 30. The sub-basin wise area and bioresidues available for areca (*Areca catechu*) and coconut (*Cocos nucifera*) are given in Tables 9 and 10 respectively. These residues (and bagasse during seasons) are most commonly used as a source of fuel for water heating. Bagasse is the fibrous residue left after extracting the juice from sugarcane (*Saccharum officinarum*). The quantity of bagasse depends on the fibrous content of the sugarcane and is in the range of 30–32%, which is a rich energy source. The area under sugarcane in the river basin is 281.82 ha with a production of 17,094 tonnes. The bagasse available is about 5470.08 tonnes, which has an energy equivalent of 19145.28 million kcal/year. One tonne of bagasse can generate 2.5 tonne of steam in steam generators. Bagasse is used as a fuel in improved jaggery making stoves in Baniga village of Hosanagara Taluk. With this, the plant has attained self-sufficiency in terms of fuel requirement. This technology has not reached all places in the river basin, which is evident from the survey that most households still use, huge wooden logs in traditional stoves (with efficiency of 5–8%).

Table 10: Biomass availability from coconut residues

Sub-basin	Coconut (ha)	Nuts (tonnes)	Leaves (tonnes)	Inflorescence (tonnes)	Husk (tonnes)	Nut/shells (tonnes)	Leaf sheath (tonnes)
Nagodiholé	9.05	10858	53.26	9.86	16.29	42.80	5.61
Haridravathiholé	127.87	153439	752.62	139.37	230.16	604.80	79.28
Hilkunjiholé	13.51	16210	79.51	14.72	24.31	63.89	8.37
Central zone	211.20	253447	1243.10	230.21	380.17	999.00	130.94
Mavinaholé	21.43	25713	126.12	23.36	38.57	101.35	13.28
Nandiholé	62.43	74920	367.48	68.05	112.38	295.31	38.71
Sharavathi	64.19	77028	377.82	69.97	115.54	303.61	39.80
Yenneholé	11.33	13597	66.69	12.35	20.39	53.59	7.03
Total	521.01	625213	3066.67	567.90	937.81	2464.38	323.03

Table 11: Sub-basin wise livestock population and dung yield

		Dungyield			Dung yield	
Sub-basin	Buffalo population	High (kg/day)	Low (kg/day	Cattle population	High (kg/day)	Low (kg/day)
Nagodiholé	1008	15120.0	12096	3106	23295.0	9318
Central zone	12510	187650.0	150120	29218	219135.0	87654
Nandiholé	818	12270.0	9816	1761	13207.5	5283
Haridravathiholé	6011	90165.0	72132	20471	153532.5	61413
Yenneholé	1850	27750.0	22200	7913	59347.5	23739
Hurliholé	2285	34275.0	27420	3350	25125.0	10050
Sharavathi	2168	32520.0	26016	6303	47272.5	18909
Hilkunjiholé	2416	36240.0	28992	3708	27810.0	11124
Mavinaholé	67533	640702.5	363645	6490	48675.0	19470

Agricultural households own 5–6 animals (considerably high number) for manure, tilling and transportation purposes. Free fodder availability due to vast grazing areas in the region has contributed to higher number of livestock per household. Table 11 show sub-basin wise livestock population and dung yield, while Table 12 gives the biogas availability with potential for cooking energy. The dung yield by livestock depends on various factors and differs from place to place. Usually the effective dung available from stall-fed animals is more than that of grazing animals. Similarly, dung available during monsoon and winter is more due to the availability of sufficient green fodder compared to summer. It is estimated from the survey that, the average dung yield by various livestock is 7.82 kg/cattle/day, 12.64 kg/buffalo/day, 10.3 kg/bullock/day, 1.95 kg/sheep/day and 1.95 kg/goat/day. Table 13 shows the extent of stall-feeding and open grazing by different livestock. Grazing in forests reduces the effective dung available and also harms forest regeneration.

Table 12: Sub-basin wise biogas availability with potential for cooking energy

Sub-basin	Human population	With maximum efficiency Biogas (m^3/day)	Usage	% Potential	With minimum efficiency Biogas (m^3/day)	Usage	% Potential
Nagodiholé	3155	1613.43	548.56	17.38	770.90	262.11	8.30
Central zone	54313	17084.97	5808.88	10.69	8559.86	2910.35	5.35
Nandiholé	14542	3758.89	1278.02	8.78	1835.67	624.13	4.29
Haridravathiholé	31371	10235.29	3480.00	11.09	4807.62	1634.59	5.21
Yenneholé	6780	3658.09	1243.75	18.34	1653.80	562.29	8.29
Hurliholé	7501	2494.80	848.23	11.30	1348.92	458.63	6.11
Sharavathi	11247	3351.28	1139.43	10.13	1617.30	549.88	4.88
Hilkunjiholé	6200	2690.10	914.63	14.75	1444.17	491.01	7.91
Mavinaholé	10158	3409.87	1159.35	11.41	1675.83	569.78	5.61
Total	145267	48296.74	16420.89	11.30	23714.09	8062.79	5.55

Table 13: Extent of stall feeding and open grazing by different livestock

Type of livestock	% Householdswith livestock	% Households with open grazing livestock	% Households with stall feeding livestock
Buffalo	74.94	66.9	33.13
Bullock	34.90	9.0	91.00
Cattle	73.10	95.1	4.89

Table 14 illustrates the role of family income in energy transition as biogas plants are found more in high-income households. However, there are several non-operational biogas plants due to technical snags. This necessitates proper training and awareness among the villagers as well as local service units with trained technicians to handle energy efficient devices. Among the 91 surveyed landless, low-income category households, none of them had biogas plants mainly due to high installation cost, space limitation and lack of service support in post installation period.

Table 15 shows the relative share of various fuel types in the river basin. In all the sub-basins, nearly 90% of energy potential is of forest resources. This also accounts for energy used in the commercial sectors such as hotels, and fuelwood used during festivals, etc., which is about 30% of the total energy consumption. To understand the sub-basin wise bioenergy status, percentage share of energy demand to the availability is computed and is listed in Table 16. This reveals that Hilkunjiholé (61.8%) and Haridravathiholé (57.2%) sub-basins need immediate intervention to prevent further degradation of natural resources. Central zone, Nandiholé, Sharavathi and Mavinaholé sub-basins are having moderate availability of resources.

Table 14: Income-wise biogas distribution in the river basin

Income range (Rupees/year)	Number of households having biogas plants among sampled households	Category-wise percentage of biogas plant holders
00000–15000	1	0.58
15000–25000	7	5.22
25000–50000	10	13.33
50000–100000	6	28.57
>100000	19	76.00

Table 15: Percentage share of energy from various sources

Sub-basin	% Share of Forest resource	% Share of Biogas	% Share of Coconut	% Share of Areca
Nagodiholé	93.73	1.31	0.19	4.76
Central zone	90.41	2.35	0.77	6.47
Nandiholé	89.99	0.65	0.99	8.37
Haridravathiholé	90.56	3.81	1.28	4.36
Yenneholé	96.88	0.99	0.08	2.05
Hurliholé	92.19	1.53	0.00	6.28
Sharavathi	88.10	2.82	1.40	7.64
Hilkunjiholé	88.13	5.72	0.74	5.41
Mavinaholé	91.57	2.89	0.48	5.06
Total	91.72	2.18	0.66	5.44

2.3. Role of JFPM in Energy Development

The participatory approach in forest management with 23VFCs was initiated in the study area in 1996. The data of 10VFCs illustrates that about 286 ha of land was brought under plantations, within which, 215 ha was of Non-Timber Forest Produce (NTFP) type and remaining 71 ha was of Acacia plantation to cater the fuelwood requirement.

The data collected on the plantation activities in sampledVFCs show that the scheme formulated from ecological and energy point of view has lost its significance due to the improper selection of species and plantation area. The vital objective of the JFPM scheme to fulfil the daily fuel, fodder and food requirement of the local population is deprived due to monoculture plantations. Apart from this, VFCs failure in protecting the degraded land and forest patches is leading to considerable decrease in regeneration.

Land use analysis (Table 17) shows that Haridravathiholé has about 34.7% barren area. Similarly, in all the sub-basins, the percentage barren lands available ranges between 10 and 35%. Thus, there is greater scope for initiating energy plantations in

Table 16: Sub-basin wise energy demand and availability

Sub-basin	Energy availability (million kcal)					Energy demand (million kcal)	% Usage
	Forest	Biogas	Coconut	Areca	Total		
Nagodiholé	166404.15	2323.65	348.28	8453.05	177529.13	22148.10	12.47
Central zone	960681.87	24992.17	8129.38	68763.75	1062567.17	381277.26	35.88
Nandiholé	217872.00	1572.55	2403.09	20253.66	242101.30	104850.70	43.31
Haridravathiholé	348667.65	14660.07	4921.61	16767.59	385016.92	220224.42	57.20
Yenneholé	505737.45	5176.71	436.13	10688.80	522039.09	47595.60	9.12
Hurliholé	226264.95	3745.89	———	15420.31	245431.15	52657.02	21.45
Sharavathi	151040.25	4842.13	2470.70	13093.58	171446.66	78951.60	46.05
Hilkunjiholé	62049.15	4029.05	519.93	3805.68	70403.81	43524.00	61.82
Mavinaholé	156991.05	4956.28	824.76	8679.39	171451.48	71309.16	41.59
Total	2795708.52	66298.50	20053.88	165925.81	3047986.71	1022537.90	33.55

Table 17: Details of barren area in the river basin

Sub-basin	Total area (sq. km)	Barren area (sq. km)	% Barren area
Haridravathiholé	278.9	96.78	34.70
Hilkunjiholé	85.1	10.10	11.86
Hurliholé	97.8	19.80	20.22
Mavinaholé	95.1	21.27	22.37
Nagodiholé	65.1	8.31	12.74
Nandiholé	143.6	42.34	29.48
Sharavathi	119.4	20.61	17.26
Yenneholé	189.0	37.47	19.82
Central zone	540.5	131.95	24.41

the eastern clusters where there is urgent requirement for energy planning. The selection of the species considering the local needs in terms of fuel, food and fodder, through active public participation will ensure the success of the programme.

2.4. Integrated Energy Planning

Analysis at the sub-basin level illustrated that the energy situation varies within various sub-basins and correspondingly the management strategies need to be designed. Decentralized approach can be considered for planning the energy interventions. By introducing the improved fuelwood cook stoves, fuelwood consumption can be reduced considerably. Because, the most commonly used traditional cook stoves have very less efficiency of 10%. Fuel efficiency studies (Ramchandra et al, 2000) conducted in 82 households showed that for cooking, there is a fuel saving of 42% in improved stoves compared to traditional stoves, whereas, for water heating, the fuel saving is 19–24% with improved stoves. Use of improved stoves for cooking activity and water heating can save annually about 38,600 tonnes and 16,507 tonnes of fuel wood respectively.

Along with this, restriction on open grazing in the forestlands and promotion of stall-feeding allows regeneration and increases the effective dung availability. Thus, appropriate livestock rearing with the introduction of improved varieties along with natives would enhance the dung yield for biogas as well as manure. According to the data, about 88% of the total households have the potential to install biogas plants. At least 60% utilization of this resource can lead to fuelwood saving of 8839.8 tonnes annually. The estimation shows that about 119 villages have the potential to supplement the cooking energy for more than 60% of the total population.

Monsoon paddy cultivation is practiced in the study area. After the crop is harvested, the fields are kept unused until the next season. In this regard, farmers need to be properly guided to suitably select the cropping system depending on water availability such as cultivating horse gram in areas where moisture content is less. Fodder cultivation can supplement fodder requirement for the livestock, which can be stall-fed considerably, there by increasing the dung yield.

The Gram Panchayath (at village level), Revenue and Forest Departments should take active participation in energy planning and development. With proper training to the village people as well as departmental staffs, it is possible to manage their own ecosystem with effective scientific guidance. JFPMoffers an opportunity to increase the forest wealth of the region. If sufficient protection is provided, the forests in the study area, though under extensive population pressure, can retain self-regenerating capacity due to highly favourable environmental conditions. If this protection is extended to other degraded areas of the river basin with complete protection from destructive wood collection, grazing by animals, etc., there is tremendous scope for re-establishing the healthy forests in most of the study area.

3. CONCLUSIONS

Based on the survey, it was found that the per capita fuelwood consumption for cooking and water heating, which are the major end-uses of the energy consumption, is 1.2 tonnes/year. As per the data, some of the eastern and southern sub-basins are facing scarcity of resources and there is a large scope for energy plantations in the degraded forestlands. Viable alternatives like biogas will help in meeting the energy demand efficiently for the river basin. The analysis shows that about 88% of the total households have the potential to install biogas plants. At least 60% utilization of this resource can lead to fuelwood saving of 8840 tonnes annually. The estimation shows that in 119 villages, biogas has the potential to supplement the cooking energy of more than 60% of the total population.

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REFERENCES

Srinivasan, H.R.,*Gobar gas-Retrospect and Prospects,* Director of Gobar Gas Scheme, Khadi and Village Industries Commission, Bombay, 1979.

United Nations Environment Programme,*Guidebook on Biogas Development,* United Nation Publication, 1980.

Ministry of Non-conventional Energy Sources Annual Report, MNES, New Delhi, India, 2003.

Kumar, S.S.,*Carrying Capacity Based Regional Development Planning-Towards Evolving a General Framework,*Regional Environmental Management Plan-Issues and Approaches, Tata Energy Research Institute, Bombay, 1999.

Ramachandra, T.V., Subramanian, D.K., Joshi, N.V., Gunaga, S.V. and Harikanthra, R.B., End Use Efficiencies in the Domestic Sector of Uttara Kannada District,*Energy Conversion and Management,* 2000, 41, 833–845.

Datye, K.R.,*Banking on Biomass,* Centre for Environmental Education, Ahmedabad, India, 1997, 25–29.

Rene Karottki and Gunnar Boye Olesen,*Biogas in India: A Sustainable Energy Success Story,* Implementing Sustainable Development, 1997. http://www.ecouncil.ac.cr/rio/ focus/report/ english/inforse.htm.

Goswami K. P. and Sutar, R.F., *Human Safety Consideration in Evolving Biogas Technology,* Changing Villages, 1993, Oct-Dec, 190–197.

John S. Holtzman,*Stall Feeding of Cattle in the Mandara Mountains of Northern Cameroon,* Overseas Development Institute, Regent's park London, 1986. http://www.odi.org.uk/ pdn/ papers/24a.pdf.

Ravindranath, N. H. and Hall, D.O., *Biomass, Energy, and Environment,* Oxford University Press, Oxford, 1995.

Ramachandra, T.V., Subramanian, D.K., Joshi, N.V., Gunaga, S.V. and Haritantra R.B., Domestic Energy Consumption Patterns in Uttara Kannada District, Karnataka State, India,*Energy Conservation and Management,* 2000a, 41, 775–831.

Sinha, C.H., Ramana, P. V. and Joshi, V.,*Rural Energy Planning in India: Designing Effective Intervention Strategies in Rural and Renewable Energy: Perspectives from Developing Countries,* Tata Energy Research Institute, India, 1997, 5–16.

Ramachandra, T.V., Joshi, N.V. and Subramanian, D.K., Present and Perspective Role of Bioenergy in Regional Energy System,*Renewable and Sustainable Energy Reviews,* 2000b, 4, 375–430.