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INTEGRATING ENERGY FLOW MANAGEMENT FOR AGRICULTURAL SUSTAINABILITY IN TRIBAL VILLAGES OF SOUTHERN ODISHA

Ananya Ramesh Patra and Surya Narayan Das

Department of Botany, Berhampur University, Berhampur, Odisha, India.

Abstract: Hill agriculture, characterized by undulating terrains and intricate poly-culture and agroforestry systems, serves as a vital livelihood source for human inhabitants. Employing traditional cultivation methods on ridges and valleys, small-scale farmers achieve remarkable productivity and stability, yielding high returns per unit of labor and energy. This agricultural approach mirrors natural ecosystems, boasting a rich organic environment, disease-resistant biodiversity, and inherent stability. Despite relying predominantly on rainfed methods, the sustainability of hill agriculture has endured through centuries of practice. This paper delves into the unique characteristics and sustainability of hill agriculture, drawing parallels between its practices and natural ecosystem dynamics. Through an exploration of traditional cultivation techniques and their alignment with ecological principles, it elucidates the resilience and productivity inherent in this agricultural approach. In light of increasing environmental pressures and changing socio-economic dynamics, it advocates for the preservation and promotion of traditional agricultural practices. This study contributes to a deeper understanding of the intricate relationships between human societies, natural ecosystems, and agricultural practices in hill regions. It highlights the importance of adopting holistic approaches that prioritize ecological integrity, socio-economic equity, and cultural preservation. Through informed policy interventions and community-led initiatives, hill agriculture can continue to thrive as a resilient and sustainable livelihood strategy, nourishing both people and the planet.

Keywords: Hill agriculture, Poly-culture, Agroforestry, Sustainability, Traditional cultivation

INTRODUCTION

Hill agriculture lands are undulating sites where human inhabitants engage in complex poly-culture and agroforestry practices. The traditional cultivation methods on the ridges and in valleys by small farmers prove reasonably productive and stable, exhibiting a high return per unit of labor and energy (Netting, 1993). This type of agriculture closely resembles natural ecosystems, not only in physical structure but also in terms of the organic environment, disease-resistant rich biodiversity, and stability. Despite being mostly rainfed, the sustainability of this agriculture practice has been proven over centuries.

Small and marginal farmers cultivate using long-tested traditional varieties, showcasing a lack of reliance on genetic conservation and taxonomy knowledge. However, their farming practices indirectly contribute to the conservation of biodiversity, making them key players in maintaining the sustainable natural gene pool. Ethnic tribal communities residing in remote hilly areas practice subsistence organic farming, utilizing natural resources such as soil and water. They cultivate in small-scale diversified systems, employing local resources and complex crop arrangements in valleys and slopes. These people, living in tropical hilly regions, are extremely poor, relying on the vast, diverse and risk-prone marginal environment (Conway, 1997).

A scientific ecological approach is crucial to developing systems and technology tailored to the specific environmental and socio-economic conditions of small farmers without increasing risk or dependence on external inputs. Agro-ecosystems should be resource conserving yet highly productive systems, incorporating practices such as polyculture, agroforestry and the integration of crop and livestock (Altieri, 1995). Understanding and appreciating the services provided by various ecosystems, including agro-ecosystems, could help address the challenges of ecosystem management for long-term sustainable food production.

The study on the flow of energy through an ecosystem is useful in understanding its functioning (Loucks and Dalesio, 1975). Traditional hill and hinterland agricultural production systems in India are solar-powered ecosystems (Mitchell, 1979), as all work depends on solar energy to produce crops, ultimately consumed by humans and animals. The present study analyzes the energy budget of crop production in hill agro-ecosystems of the Niyamgiri range in Rayagada district, Odisha, situated in the eastern part of India. The study also discusses the interrelation between agro- and natural ecosystems.

The Niyamgiri Hill Range comprises about 164 villages dependent on forest resources for their livelihood. The magnitude of changes due to the interdependency of agro-ecosystems and forest ecosystems has led to both ecological and economic erosion.

LITERATURE REVIEW

Various studies on tribal village ecosystems in India have addressed biomass production, consumption, material and energy dynamics (Rabindranath et al., 1981; Nisanka and Mishra, 1990; Nayak et al., 1993). The tribal village ecosystem in India primarily functions by recycling resources within the system (Mishra and Ramakrishnan, 1982), and the practice of converting forest to agriculture by tribal people has been a traditional cultivation method (Schenldar, 1995; Anderson, 1990). The ecosystem is dynamic, and model cultivation practices must be developed in tropical areas to address converted ecosystems (FAO, 1993).

The tribal population traditionally maintains a close connection with nature, and studying their relationship with the environment provides insights into socioeconomic and cultural links within the ecosystem (Sahoo and Misra, 1992; Rao et al., 2003). Biomass energy and human labor are driving forces for the functioning of agriculture-based village ecosystems (Nisanka and Mishra, 1989; Rao et al., 2003). Ecologists have attempted to correlate changes in plant and animal diversity with different scales of natural/anthropogenic disturbances (Van Der Maarel, 1993; Nautiyal et al., 2003; Maikhuri et al., 2004), emphasizing the need to improve agro-ecosystem production through rainwater management, the application of organic manure, protection of existing forests, and agroforestry practices (Dash and Mishra, 2001).

Traditional resource management and agroforestry systems may lead to improvements in livelihoods through the simultaneous production of food, fodder, and firewood, as well as the mitigation of the impact of climate change (Rabindranath and Hall, 1995).

Agroforestry systems may provide part of the answer to the challenge of sustainability, that is how to conserve forest ecosystems and farmland biodiversity, along with the services they provide, while simultaneously enhancing food production for an increasing population under conditions of land and water scarcity (Lambin and Meyfroidt, 2011; Godfray et al., 2010; Phalan et al., 2011). The villages in and around the Niyamgiri Hill Range derive their livelihoods from forest resources. The practice of traditional agriculture and the interdependency of the agro-ecosystem and the forest ecosystem have impacted both ecological and economic conditions in these ecosystems. Studies of ecosystem linkages and socio-cultural changes are essential to develop strategies to arrest further degradation of the ecosystem and suggest priority sectors for improvement.

Study objectives

The current study focuses on the energetics of the village agro-ecosystem surrounding Niyamgiri forests, aiming to propose strategies for achieving conservation objectives and ensuring the compatibility of the village ecosystem with ecological requirements. The sustainability of the agro-ecosystem, its dependency on the forest ecosystem, and the economic development of the community were examined in terms of resource and energy flow, with the following major objectives:

1. To investigate agricultural practices, animal husbandry and other economic activities in villages around the Niyamgiri Forest.
2. To assess the impact of various practices on society and the forest, considering changes in culture and tradition.
3. To compare energy dynamics between villages closer to urban areas and those farther away from urban centers.
4. To identify linkages between the human community and the forest ecosystem and propose a sustainable model.

MATERIALS AND METHODS

Study area overview

The Niyamgiri Hill Ranges extend across four blocks in the Rayagada District of Odisha, India. For this study, the Bissam Cuttack block was chosen due to the accessibility of villages. The Niyamgiri hill range is predominantly covered by Shorea robusta forest, and the practice of shifting (Podu) cultivation is widespread. The tribal population residing in the range belongs to the Kandha tribe, specifically the 'Dongria Kandha,' considered a primitive tribal group settled in high-altitude areas above 600 to 700 m elevation.

For the study of agro-ecosystems, four villages at higher elevations inside the Niyamgiri Forest and four villages situated at the foothills of Niyamgiri were selected. Among the foothill villages, two are closer to the market place (urban area), and two are a bit farther away. The villages inside Niyamgiri Hill Forest at higher altitudes include Patlamba, Rodanga, Khajuri and Gortali. The villages at the foothills away from the market place are Majhihalma and Bhaliabhatta. The villages on the foothills located nearer to the market place are D. Kumbharbadi and Papikhunti. In total, eight villages were selected for the study. The physical location map of the study area is depicted in Figure 1.

Methodology

The tropical monsoon in the region contributes an annual rainfall of 1100 to 1500 mm, primarily concentrated during the rainy season from July to September. Temperature variations in the district ranged from 6.5 to 30°C between 2009 and 2013, with relative humidity fluctuating between 40% (March) and 85% (July). The Niyamgiri forest is of the tropical dry deciduous type, predominantly featuring Sal and its associates.

Comprehensive information on the selected villages was collected through a questionnaire-cum-schedule (Annexure A). The questionnaire design drew inspiration from methods employed by Reddy (1982), Nisanka and Mishra (1989, 1990), Singh and Singh (1992), Nayak et al. (1993), and Sahoo (1993). Socio-economic data and ecological parameters of the villages were gathered during the period 2010 to 2015. Regular visits were made to the sampled villages to collect data, primarily through interviews with the family heads. Data collection began in 2010 to 2011, with individual family information recorded in the village through participatory rural appraisal (PRA) exercises. A comprehensive inventory was created, covering various aspects such as area under different crops, cropping patterns, yields, area under irrigated and rainfed crops, labor input in terms of animals and human beings, fertilizer input in terms of manure and chemicals, seed input, crop production, crop by-products, fodder requirement of livestock population, sources and supply of fodder.

An estimate of animate energy input into different crop entities was done separately. The hours spent per unit area (ha) of crops were determined by counting the total number of working men, women, children and draught animal pairs (DAP), and calculating the total hours spent by each for various agricultural operations. Total hours spent for each crop were then calculated based on the respective crop area. Energy efficiency of each system was calculated as the output-input ratio. Output was determined as the agronomic yield of the crop (grain, tuber and other edible plant parts) and the yield of crop by-products (fodder output) following Mitchell (1979). Energy equivalents were based on data from Gopalan et al. (1978) and Pimentel and Pimentel (1979), expressed on a fresh weight basis. The energy budget was calculated separately for each crop.

The study of energy flow through the village ecosystems considered both animate (human and animal) and inanimate (food, fodder, fuel and thatching material) energy sources. The energy content of imported and exported materials was expressed to estimate the inflows and outflows of energy.

RESULTS AND DISCUSSION

The human population in the uphill villages ranges from 83 to 312, while foothill villages have populations between 76 and 150. The total human population across all villages is 800, comprising approximately 500 males and 300 females, with an age distribution of 200, 500 and 100 for the age groups <1-15, 16-59 and 60+ years, respectively. The animal population consists of 90 cows, 150 buffaloes, 148 bullocks, 234 goats and 30 horses. The cultivated area represents 3.37 to 18.85% of the total geographical area of the village, with per capita cultivated area varying from 0.117 to 0.329 ha (Table 1).

Despite the limited cultivation area, families actively engage in agriculture, supporting each other in the practice. The remaining time is often dedicated to the collection of Minor Forest Products (MFP) for livelihood support.

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Primarily, women and children gather various leafy vegetables, tubers, mango (green and ripe), siali leaf and mahua flowers. During the rainy season, when agricultural work is less intense, the collection and marketing of firewood in headloads become common. Firewood plays a significant role in the energy flow, contributing 53.02 to 69.52% of the total energy flow of the villages (Table 2).

This energy flow underscores the village community's dependence on the forest ecosystem. Other MFP, bamboo and small timber/poles collected from the forest further enhance the participation of forest products in the total energy flow of the village ecosystem. The total human energy spent on the collection of MFP, bamboo and firewood was 101.65 GJ in Patlamba, 171.21 GJ in Rodanga, 178.09 GJ in Khajuri, 102.69 GJ in Gortali, 92.739 GJ in Majhihalma, 36.41 GJ in Bhaliabhatta, 72.96 GJ in D. Kumbharbadi, and 37.96 GJ in Papikhunti (Tables 4 to 11). The forest cover in Rayagada district has been subject to various biotic interferences, leading to qualitative changes according to reports from the forest survey of India. While the area of forest cover has not been significantly affected, the quality of the forest has undergone changes (Table 3). This indicates the need for appropriate measures to restore the forest and enhance its productivity.

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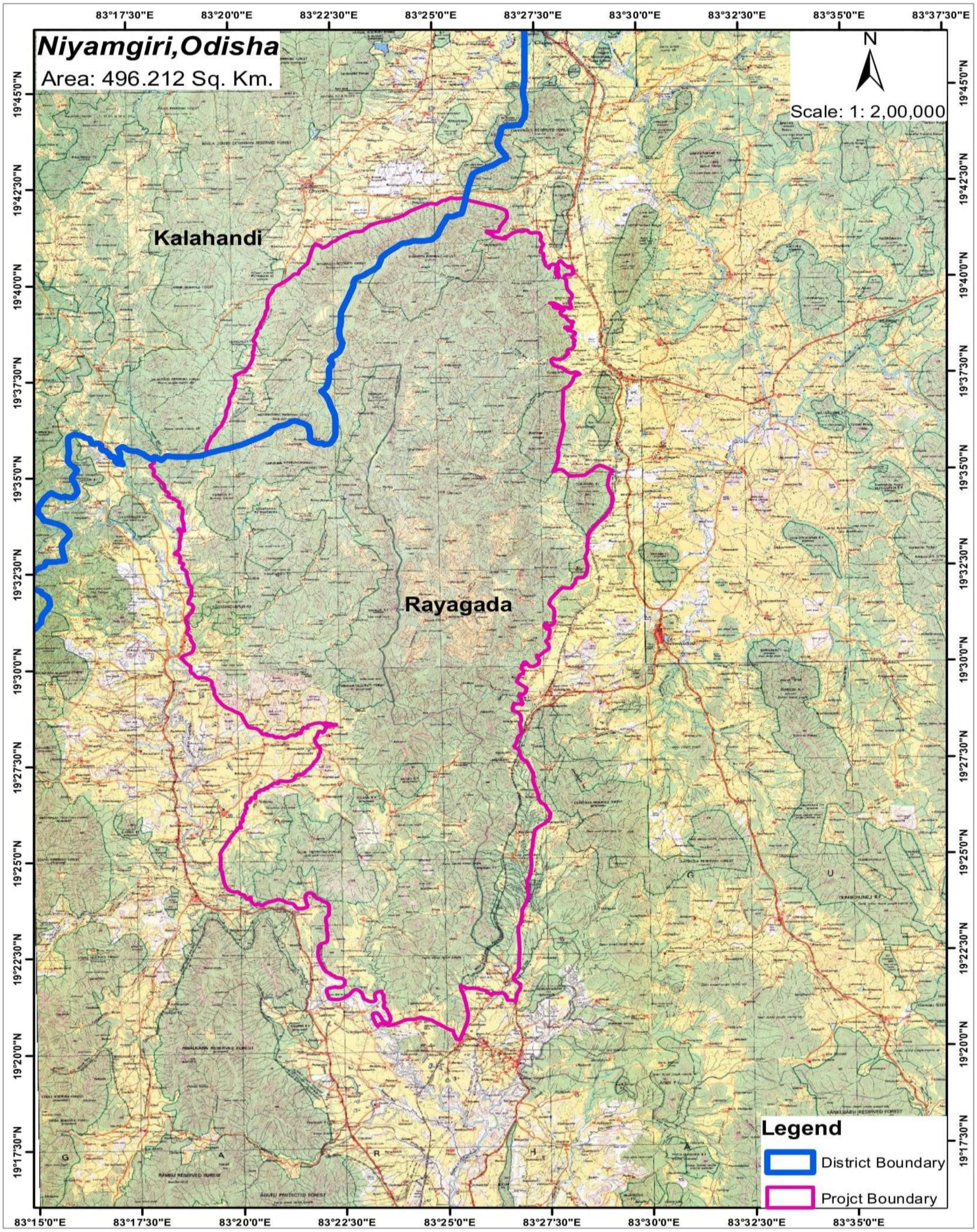

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Figure 1. Topo-map of study area in Rayagada and Kalahandi districts.

Table 1. Structural analysis of village ecosystem.

Village data	Village							
	P	**R**	**K**	**G**	**M**	**B**	**D**	**H**
Total household	22	60	61	39	36	18	26	16
Total human population	83	279	312	201	150	90	100	76
Total male	32	129	140	87	72	44	47	45
Total female	51	150	172	114	78	46	53	31
Male:female	1:1.59	1:1.16	1:1.22	1:1.31	1:1.08	1:1.04	1:1.12	1:0.68
Average family size	3.8	4.65	5.1	5.2	4.2	5.0	3.8	4.8
Literacy rate (%)	4.8	21.86	39.4	13.9	48.0	21.1	72.0	50.0
Total livestock population	200	218	334	383	341	112	131	176
Cow	4	16	22	25	39	0	29	21
Bullock	0	6	0	0	0	19	0	6
Buffalo	0	7	0	0	0	7	0	16
Goat	83	51	67	86	78	13	42	26
Sheep	0	33	0	0	0	0	0	2
Poultry	90	90	77	173	140	73	37	99
Pig	23	15	168	99	84	0	23	6
Land use pattern								
Total land area (ha)	157.97	297.75	307.66	259.23	624.17	60.61	250.16	173.72
Aquatic	0	0	1.15	0	0	0.52	2.12	0
Housing	0.06	0.29	0.36	0.36	0.33	0.40	0.17	0.16
Uphill shifting cultivation	5.46	13.52	19.14	14.21	9.028	4.129	7.854	7.328
Mid hill (orchard)	3.1	27.83	36.68	20.43	0.1	0.04	0.1	0.06
Home-garden (Vegetables)	0.61	5.18	3.24	3.04	8.06	3.40	7.11	15.20
Valley paddy	0	7.22	0	0	10.84	3.46	13.07	0.00
Valley maize	0.566	1.235	10.809	9.514	8.016	4.574	4.777	0.554
Per capita agricultural land orchard (in Ha)	0.117	0.197	0.223	0.234	0.240	0.173	0.329	0.304

P, Patlamba; R, Rodanga; K, Khajuri; G, Gortali; M, Majhihalma; B, Bhaliabhatta; D, D. kumbharbadi; H, Papikhunti.

Table 2. Share of firewood in village energy flow (GJ).

Village	Total energy flow	Share of firewood energy	Percentage of firewood energy
Patlamba	6000.37	3798	63.29
Rodanga	9852.59	6285	63.79
Khajuri	10249.25	6390	62.34
Gortali	6407.36	3397.50	53.02
Majhihalma	5585.05	3885	69.52
Bhaliabhatta	2407.70	1597.5	66.34
D. Kumbharbadi	4380.24	2955	67.46
Papikhunti	2591.59	1522.50	58.74

All the villages under study rely on rain-fed agriculture, with no developed irrigation facilities. However, natural stream water is available to paddy fields through gravity flow. Four categories of agriculture practices are prevalent in the villages: (i) Podu cultivation in high hill areas, (ii) mid-hill orchards below the podu area, (iii) home gardens adjoining habitation, and (iv) valley cultivation near Nala beds, typically at lower heights of habitations. Podu cultivation involves mixed cropping of cereals, pulses and oilseeds, demonstrating a sustainable approach with optimal space and time utilization. Mid-hill orchards, featuring horticultural trees such as mango, orange and pineapple yield good annual returns. Home garden cultivation is less common in uphill villages, relying on forest collection for domestic vegetable needs, while foothill villages emphasize vegetable production and sale. Among all villages, Papikhunti stands out for its robust home garden products like brinjal, tomato, lady's finger, and simba. Rice production is practiced in one uphill village (Rodanga) and three foothill villages.

The human energy invested in agriculture in uphill villages ranged from 2.23 to 3.44 GJ ha-1, while in foothill villages, it varied from 1.78 to 2.41 GJ ha-1 (Table 4). The analysis of material flow related to the food component considered the export-import ratio (Table 5). The importexport ratio of food energy flow in different villages indicates the self-sufficiency of the village ecosystem in food production. The village D. Kumbharbadi, closest to the urban area, has the highest export-import ratio (55.29), followed by Gortali (1.105) and Khajuri (1.09).

This suggests that the village nearest to the urban area has the ability to produce the highest food energy compared to other villages under study. Villages away from urban areas have lower export-import ratios (Majhihalma- 0.03, Bhaliabhatta- 0.04), indicating the impact of the urban area on village economic activities. These villagers are required to import more food commodities from outside the village ecosystem compared to others.

The animal husbandry sub-system is poorly developed in these villages, with no milk produced in uphill villages. Buffalo milk production was recorded from foothill villages: Majhihalma at 14 L/day, Bhaliabhatta 15 L/day, D. Kumbharbadi 18 L/day and Papikhunti 25 L/day. In the energy flow of the village, the export of minor forest products (MFP) is a major component (mainly siali leaf, hill broom, mango, tamarind etc.) and highlights the importance and role of the forest in the village economy. The production of agricultural and animal components was mostly utilized inside the village as food, fodder, fuel, etc. Some agricultural products like cereals and pulses were sold, treated as exports of the village. Some food items like rice, vegetables, kerosene, dry fish, etc. were purchased from the local market, treated as imports to the village ecosystem. Similarly, items like firewood and bamboo sold outside were treated as export value. Village-wise data on production, consumption, import, and export are given in Tables 6 to 13 for each village to assess the energy flow.

Table 3. Change dynamics of forest cover of Rayagada district in sq.km (FSI, 2021).

Year of FSI report	1999	2013	2013	2017	2021
District geographical area (DGA)	7580	7580	7580	7580	7073
Very dense forest	-	13	428	422.	373
Dense forest	972	-	-	-	-
Moderately dense forest	-	1,085	860	853	1145
Open forest	1728	1,963	1845	1851	1622
Scrub forest	806.	3,061	279	349	357
Percent of DGA	35.62	43.28	44.3	44.2	33.5

Table 4. Human energy input in agriculture (GJ ha^{-1}).

Village	Cultivated area	Total human energy	Human energy per hectare
Patlamba	12.36	27.64	2.23
Rodanga	56.14	161.19	2.87
Khajuri	57.37	197.39	3.44
Gortali	37.25	124.79	3.35
Majhihalma	21.07	50.92	2.41
Bhaliabhatta	9.93	22.73	2.28
D. Kumbharbadi	24.72	44.02	1.78
Papikhunti	21.73	38.70	1.78

Table 5. Export-import of food energy values in GJ and ratio in study villages.

Uphill villages	Patlamba	Rodanga	Khajuri	Gortali
Export	31.70	306.02	419.87	269.68
Import	138.59	484.29	381.86	243.89
Ratio	0.23	0.63	1.09	1.105

Foot hill villages	Majhihalma	Bhaliabhatta	D. Kumbharbadi	Papikhunti
Export	7.15	4.67	167.29	17.17
Import	224.90	112.85	3.03	100.44
Ratio	0.03	0.04	55.29	0.17

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The millennium ecosystem assessment (MA) (2005) suggests that in the next 50 to 100 years, major agricultural decisions will involve trade-offs, especially between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity (Nelson, 2005). Brooker et al. (2014) point out that with growing demand for food production and water use, demands on ecosystem services could surpass the capacity of certain ecosystems to supply these services. So, a balance between the production of various services in the ecosystem and the social and economic benefits and risks of using technology is crucial (Brooker et al., 2014).

Traditional agricultural systems have evolved into diverse agro-ecosystems, some of which are rich in biodiversity and provide ecosystem services in addition to food production. Examples include wet rice-poultry farming systems and the practice of increased diversity of crop varieties within farmers' fields, which have been shown to reduce the risk of crop loss to pest diseases (Jarvis et al., 2007; Mulumba et al., 2012).

Agro-forestry systems may provide part of the answer to the challenge of sustainability by conserving forest ecosystems and farmland biodiversity, as well as the services they provide, while simultaneously enhancing food production for an increasing population under conditions of land and water scarcity (Lambin and Meyfroidt, 2011; Godfray et al., 2010; Phalan et al., 2011). Research is needed to explore alternative agricultural strategies and understand how more biologically complex systems may present short and long-term environmental and socio-economic benefits, such as enhanced food security, ecosystem service provisioning, and agricultural resilience to environmental change (Altieri, 1980; Tomich et al., 2011). These benefits are often assessed by comparing complex agricultural systems to intensified monocultures, which are widely associated with reduced biodiversity (Tscharntke et al., 2005), disruption of biogeochemical processes (Drinkwater and Snapp, 2007), and large contributions to local and global climate change (Robertson et al., 2000).

Taking major components into account, such as food, minor forest products (MFP), fodder and fuel production, the highest energy production was recorded for the village Khajuri (10,249.25 GJ year-1), followed by Rodanga (9,852.59 GJ year^{-1}), Gortali (6,407.36 GJ year^{1}) and Patlamba (6,000.37 GJ year^{-1}) in the uphill villages. Among foothill villages, Majhihalma recorded the highest energy output of 5,795.33 GJ year^{-1}, followed by D. Kumbharbadi, Bhaliabhatta and Papikhunti. Rice contributes higher energy production than other agricultural products in foothill villages, while Koshala (Barnyard millet) occupies the highest position in energy production among uphill villages. The composition of production and consumption energy indicates higher energy savings in the uphill villages over the foothill villages (Table 14).

The village ecosystem comprises three major subsystems: Agriculture, animal husbandry and the domestic sub-system. All these are interrelated among themselves and with the forest ecosystem. The relationship can be described through the quantity of energy flow and its sustainability. The deficit of the village ecosystem is met by procuring materials from outside these systems. The production of the agriculture sub-system is not sufficient to meet the food requirements of the village's ecosystem. The input-output ratio of MFP collection varies from 1:38.47 (Gortali) to 1:50.46 (Bhaliabhatta), which is much higher than the agriculture production sub-system. In the agriculture sub-system, the input-output ratio varies from 1:11.63 (Rodanga) to 1:23.32 (Bhaliabhatta). In Gortali, the input of MFP collection was 102.70 GJ, and the output was 3,951.19 GJ. The highest ratio in the village Bhaliabhatta has the input value of 36.411 GJ and output value 1,830.17 GJ (Tables 6 to 13). This indicates the comparative benefit between the forest ecosystem and agriculture ecosystem. MFP collection is a "no

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investment" practice for the low-income group, which dominates in tribal pockets. It is mainly collected by female workers and children, and in effect, for family sustenance, the education of boys and girls is neglected. The contribution of MFP to energy production is very

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Table 6. Energy flow in Patlamba village ecosystem (GJ $year^{-1}$).

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	0	130.491	0	130.491	0
	Maize	2.108	2.108	0	0	0
	Finger millets (Mandia)	52.356 9.105	52.356 9.105	0	0	0
	Pearl millets (Ghantia)	29.464	29.464	0	0	0
	Common millets (Kangu)	48.99 17.25	48.99 13.78	0	0	0
	Barnyard millets (Koshala)	0.302	0.302	0	0	0
	Redgram Legumes (Kandul)	10.173	10.173	3.47	0	0
	Jhudanga	0.214 8.006	2.296	0	0	0
	Kating	0.336	1.168	0	0	0
	Vegetables		0.14	0	2.082	0
	Turmeric			6.838	0	0
Food	Ginger			0.196	0	0
	Banana	0	0	0	0	0
	Jack fruit	9.638	0.319	8.52	0	0.799
	Mango	3.321	0	3.321	0	0
	Pine apple	10.162	1.933	8.229	0	0
	Papaya	1.519	0.389	1.13	0	0
	Dry food (flour, etc.)	0	2.639	0	2.639	0
	Others (potato, etc.)	0	0.763	0	0.763	0
	Meat	1.78	1.78	0	0	0
	Dry fish (marine)	0	2.039	0	2.039	0
	Sugar	0	0.249	0	0.249	0
	Molasses	0	0.333	0	0.333	0
Sub total		204.724	310.817	31.704	138.596	0.799

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	Fruits and miscellaneous	0.55	0.55	0	0	0
	Mohua flowers	1.305	0.435 0.492	0.87	0	0
	Tamarind fruits	1.906	35.86 2.802	1.414	0	0
	Bamboo(weight)	691.12	7.728	655.26 0	0	0
	Wild tubers	2.802		74.702	0	0
Minor forest products	Mango	82.43			0	0
	Salapa rasa (Wild shap) (in L)	0.494	0.494	0	0	0
	Leafy vegetables	0.897	0.457	0.44	0	0
	Small timber/poles (in weight)	522.7	28.177	494.523	0	0
	Amla	0.462	0	0.462	0	0
	Broom grass	3.116	0.656	2.46	0	0
Sub total		1307.782	77.651	1230.131	0	0
Fodder	Other straw Crop	379.74	304.778	0	0	74.962
	residues	132.301	25.787	0	0	106.514
	Bran/ husk					
Sub total		512.041	330.565	0	0	181.476
	Firewood/fuelwood (tons)	3798	1344	2454 0	0	0
	Kerosene (tons)	0	36.96	0	36.96	0
Fuel	Dung (tons/year)	128.53	103.3		0	25.23
	Agriculture residue	49.296	45.346	0	0	3.95
Sub total		3975.826	1529.606	2454	36.96	29.09
Grand total		6000.37	2248.64	3715.84	175.56	211.37

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Table 7. Production, consumption, export, import and waste of energy in Rodanga village ecosystem (GJ year^{-1}).

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	102.089	568.503	-	466.41	-
	Maize	7.085	7.085	-	-	-
	Finger millets (Mandia)	139.98	139.98	-	-	-
	Pearl millets (Ghantia)	11.513	11.513	-	-	-
	Common millets (Kangu)	38.862	38.227	0.635	-	-
	Barnyard millets (Koshala)	150.006	147.246	2.76	-	-
	Redgram legumes (Kandul)	53.719	19.039	34.68	-	-
	Jhudanga	2.106	1.998	0.108	-	-
	Kating	23.302	21.563	1.739	-	-
	Vegetables	2.242	2.899	1.43	2.087	-
	Turmeric	150.921	3.652	147.269	-	-
	Ginger	72.324	0.336	71.988	-	-
Food	Banana	6.351	-	6.351	-	-
	Jack fruit	19.489	0.532	17.04	-	1.917
	Orange	0.226	0.0338	0.1922	-	-
	Mango	6.67	-	6.67	-	-
	Pine apple	12.871	1.096	11.775	-	-
	Papaya	6.328	2.938	3.39	-	-
	Dry food (flour)	-	7.789	-	7.789	-
	Others (Potato, etc.)	-	1.388	-	1.388	-
	Meat	5.367	5.367			
	Dry fish (marine)	-	4.58	-	4.58	-
	Sugar	-	0.832	-	0.832	-
	Molasses	-	1.2	-	1.2	-
Sub total		811.451	987.7968	306.027	484.29	1.917

Oil Seed	Castor	6.708	1.538	5.17	-	-
	Niger	1.611	1.611	-	-	-
Sub total		8.319	3.149	5.17	0	0
Minor Forest products	Tamarind fruits	4.305	0.615	3.69	-	-
	Bamboo (weight)	563.98	495.52	68.46	-	-
	Wild tubers	7.226	7.226	0	-	-
	Mango	88.872	13.211	75.66	-	-
	Salapa rasa (Wild shap) (in L)	7.6	7.6	-	-	-
	Leafy vegetables	1.355	0.704	0.651	-	-
	Small timber/poles (in weight)	296.021	251.69	44.331	-	-
	Siali leaf (in weight)	2.962	-	2.962	-	-
	Broom grass	6.232	0.984	5.248	-	-
Sub total		978.553	777.55	201.002	0	0
Fodder	Paddy straw	81.219	79.98	-	-	1.239
	Other straw	913.67	725.22	-	-	188.45
	Bran/husk (legumes and millets)	48.688	48.688	-	-	-
	Crop residues	342.347	65.036	-	-	277.31
Sub total		1385.924	918.924	0	0	467.00
Fuel	Firewood/ fuelwood (tons)	6285	2795.253	3489.75	-	-

Table 7. Contd.

	Kerosene (tons)	0	100.8	-	100.8	-
	Dung (tons/year)	238.6	190.26	-	-	48.34
	Agriculture residue	144.74	137.776	-	-	6.964

Original Article

Sub total	6668.34	3224.089	3489.75	100.8	55.304
Grand total	9852.59	5911.51	4001.95	585.09	524.22

Table 8. Energy flow in Khajuri village ecosystem (GJ year^{-1}).

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	0.00	373.54	0	373.54	0
	Maize	37.11	37.11	0	0	0
	Finger millets (Mandia)	242.92	242.92	0	0	0
	Pearl millets (Ghantia)	19.19	19.19	0	0	0
	Common millets (Kangu)	21.37	21.37	0	0	0
	Barnyard millets (Koshala)	175.19	119.99	55.2	0	0
	Redgram legumes (Kandul)	78.34	26.32	52.02	0	0
	Jhudanga	3.13	3.13	0	0	0
	Kating	41.63	41.63	0	0	0
	Vegetables	3.70	2.16	2.7885	1.2519	0
	Turmeric	88.71	3.51	85.21	0	0
	Ginger	77.67	0.42	77.25	0	0
Food	Banana	7.84	0.00	7.839	0	0
	Jack fruit	16.34	0.26	14.91	0	1.1715
	Orange	0.11	0.02	0.094	0	0
	Mango	43.79	0.00	43.792	0	0
	Pine apple	91.93	14.55	77.38	0	0
	Papaya	7.01	3.62	3.39	0	0
	Dry food (flour)	0.00	2.03	0	2.03	0
	Others (potato, etc.)	0.00	0.39	0	0.39	0
	Meat	6.35	6.35	0	0	0
	Dry fish (marine)	0.00	2.51	0	2.51	0
	Sugar	0.00	0.67	0	0.666	0

Original Article

	Molasses	0.00	1.47	0	1.4674	0
Sub total		962.34	923.15	419.87	381.86	1.17
Oil seed	Castor	27.43	1.53	25.9	0	0
	Niger	0.93	0.93	0	0	0
Sub total		28.36	2.46	25.90	0.00	0.00
Minor Forest products	Tamarind fruits	3.94	0.74	3.198	0	0
	Bamboo (weight)	502.04	489.00	13.04	0	0
	Wild tubers	8.20	8.20	0	0	0
	Mango	104.73	18.33	86.39	0	0
	Salapa rasa (Wild shap) (ton)	9.60	9.60	0	0	0
	Leafy vegetables	1.32	0.44	0.88	0	0
	Small timber/poles (weight)	265.15	265.15	0	0	0

Original Article

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	0.00	238.82	0.00	238.82	0.00
	Maize	29.69	29.69	0.00	0.00	0.00
	Finger millets (Mandia)	186.73	186.73	0.00	0.00	0.00
	Pearl millets (Ghantia)	19.34	19.34	0.00	0.00	0.00
	Common millets (Kangu)	24.96	24.96	0.00	0.00	0.00
	Barnyard millets	132.49	91.09	41.40	0.00	0.00
	(Koshala)	67.02	32.34	34.68	0.00	0.00
	Redgram legumes	3.73	3.73	0.00	0.00	0.00
	(Kandul)	34.26	16.87	17.39	0.00	0.00
	Jhudanga	3.03	1.70	2.14	0.81	0.00
	Kating	49.97	2.92	47.04	0.00	0.00
	Vegetables	49.92	0.36	49.56	0.00	0.00
	Turmeric					
Food	Ginger					
	Banana	4.19	0.00	4.19	0.00	0.00
	Jack fruit	9.12	0.70	6.39	0.00	2.03
	Orange	0.08	0.01	0.07	0.00	0.00
	Mango	32.40	0.00	32.40	0.00	0.00
	Pine apple	38.17	7.16	31.01	0.00	0.00
	Papaya	4.24	0.85	3.39	0.00	0.00
	Dry food	0.00	1.14	0.00	1.14	0.00
	Others (potato, etc.)	0.00	0.24	0.00	0.24	0.00
	Meat	4.53	4.53	0.00	0.00	0.00
	Dry fish (marine)	0.00	1.49	0.00	1.49	0.00
	Sugar	0.00	0.58	0.00	0.58	0.00
	Molasses	0.00	0.80	0.00	0.80	0.00
Sub total		693.87	666.06	269.68	243.89	2.03
Oil seed	Castor	11.81	1.30	10.51	0.00	0.00
Sub total		11.81	1.30	10.51	0.00	0.00

Original Article

	Siali leaf (weight)	3.24	0.00	3.2384	0	0
	Broom grass	7.38	1.15	6.232	0	0
Sub total		905.59	792.60	112.98	0.00	0.00
Fodder	Other straw	1111.08	913.21	0	0	197.870
	Crop residues	454.77	100.04	0	0	354.730
sub total		1565.85	1013.25	0.00	0.00	552.60
Fuel	Firewood/ fuelwood (tons)	6390.00	5190.00	1200	0	0
	Kerosene (tons)	0.00	102.48	0	102.48	0
	Dung (tons/year)	179.69	132.65	0	0	47.04
	Agriculture residue	217.42	199.90	0	0	17.52
Sub total		6787.11	5625.03	1200.00	102.48	64.56
Grand total		10249.25	8356.48	1758.75	484.34	618.33

Table 9. Energy flow in Gortali village ecosystem (GJ $year^{-1}$).

Table 9. Contd.

	Tamarind fruits	3.08	0.62	2.46	0.00	0.00
	Bamboo (weight)	281.99	281.99	0.00	0.00	0.00
	Wild tubers	4.73	4.73	0.00	0.00	0.00
	Mango	49.22	7.82	41.40	0.00	0.00
Minor forest products	*Salapa rasa* (Wild sap) (ton)	6.27	6.27	0.00	0.00	0.00
	Leafy vegetables	0.99	0.46	0.53	0.00	0.00
	Small timber/poles (weight)	185.21	185.21	0.00	0.00	0.00
	Siali leaf (weight)	15.73	0.00	15.73	0.00	0.00

Original Article

	Broom grass	6.56	0.98	5.58	0.00	0.00
Sub total		553.77	488.07	65.70	0.00	0.00
Fodder	Other straw	955.31	702.83	0.00	0.00	252.48
	Crop residues	387.80	387.80	0.00	0.00	0.00
Sub total		1343.11	1090.63	0.00	0.00	252.48
	Firewood/ fuelwood (tons)	3397.50	2662.50	735.00	0.00	0.00
	Kerosene (tons)	0.00	65.52	0.00	65.52	0.00
Fuel	Dung (tons/year)	215.76	174.77	0.00	0.00	40.99
	Agriculture residue	191.53	170.81	0.00	0.00	20.72
Sub total		3804.79	3073.61	735.00	65.52	61.71
Grand total		6407.36	5319.67	1080.88	309.41	316.22

distinct in all villages. Since the only input was human labor, the rate of return was found to be very high. Pandey and Singh (1984), while studying Kumaun Himalayan villages, observed that the agro-ecosystem of the hills is surrounded by the forest ecosystem, and a considerable amount of subsidy energy is available for the operation of hill agro-ecosystems in the form of animal fodder, wood fuel and free irrigation water from spring-fed ponds. The surrounding forest ecosystem provides 76% of the fodder requirement, the crop land ecosystem only 22%; crop residues, 11%, and the remaining 2% imported from the market. Unlike the agroecosystems of hills, Niyamgiri villages do not use dung as energy in terms of dung (manure). Dung can be used as manure to reduce pressure for fuel wood from the forest ecosystems. The villages in the hills, such as the one studied, are therefore centers of massive energy consumption. These systems are viable as long as the energy subsidy from the surrounding forest ecosystem is available. But the cost of it is tremendous. There are ever-increasing concentric circles of forest destruction around the villages.

The highest per capita food energy consumption in the village Khajuri is due to higher paddy cultivation in the valley and being nearest to the market for easy access to urban facilities. The other village Papikhunti concentrates on vegetable production, and there is no scope for paddy cultivation in the valley Nala sides. Access to the public distribution system (PDS) is better in these two villages compared to other villages. Food energy consumption in all villages is less than the average requirement of 11.7 MJ cap^{-1} day^{-1} as suggested by the National Expert Group of the Indian Council of Medical Research (Gopalan et al., 1978). The highest value of Khajuri village (11.54 MJ cap^{-1} day^{-1}) is at par with the value of 10.7 MJ cap^{-1} day^{-1} (Sahoo, 1993) but higher than the value of 9.3 MJ cap^{-1} day^{-1} for a tribal village on Mahendragiri foothills, Odisha (Nayak et al., 1993). The uphill villages depend on the variety of minor millets produced in Podu areas. In general, all villages suffer malnutrition due to insufficient food consumption. Illiteracy and addiction to low-cost liquor among tribals create health problems, which are also responsible for the deterioration of the economy.

The villagers use a traditional cooking system with "challah" where firewood (biomass) is used, and kerosene is used for lighting. Due to easy availability, stem wood and branch wood are used. Firewood collection by cutting immature trees is responsible for the deterioration of forest crops. The per capita per day consumption varies from 1.855 kg day^{-1} (Rodanga) to 3.080 kg day^{-1} (Khajuri) in uphill villages and from 2.577 kg day^{-1} (Bhaliabhatta) to 4.402 kg day^{-1} (D. Kumbharbadi) in foothill villages. The average per day consumption is lower in uphill villages compared to foothill villages. The annual per capita fuelwood consumption complex of Odisha (Sahoo, 1993), Bhogibunda tribal varies from 0.667 tons year-1 (Rodanga) to 1.585 tons village (Nayak et al., 1993), and Bhabinara-Yampur, year-1 (Khajuri), which is higher than the consumption Odisha (Nisanka and Mishra, 1990), Uchangi, Karnataka rate reported for many Indian villages such as Haripur (Mishra et al., 1983). The average fuelwood consumption per household (family) obtained in the study is within the range reported for many Indian villages. The value is comparable to the value reported for six villages of Karnataka (Reddy, 1982) and nearly similar to the value reported for Himalayan foothill villages (Pandey and Singh, 1984; Moench, 1989) but less than the tribal villages in Odisha (Mohapatra, 1992). Per capita biomass energy consumption observed in these villages is higher than the value reported by Goodman (1987), Williams (1985), and Scurlock and Hall (1990) for the rural population of developing countries. Easy access to firewood and a subsistence village

Original Article

Firewood is used as fuel energy in all villages and economy is responsible for 100% dependency on meets the family income for those selling firewood. This biomass energy. Traditional mud stoves for cooking is in agreement with the data reported for many Indian require high consumption of firewood as the heat villages of Tyviang (Gangwar and Ramakrishnan, 1987). utilization efficiency of mud challah (stoves) is only around 20.35% for firewood (Nisanka et al., 1992). PDS rice received from government schemes (imported) meets the gap. On the other hand, the uphill villages sell a good quantity of minor millets, horticulture products (jackfruit, pineapple, banana, orange and mango), which can be recorded as high energy value. The material flow table presenting the production, consumption, import, export, and waste part of major items under food, minor forest products, fodder, fuel indicates that the import is very less compared to the export (Tables 6 to 13). The import and export data of all villages detailed in Table 15 in terms of energy help to understand the level of dependence of villages on food, minor forest products, fodder and fuelwood.

Table 10. Energy flow in Majhihalma village ecosystem (GJ year^{-1}).

Production, consumption, export, import and waste of energy in Majhihalma village ecosystem (GJ year^{-1})

Source	Item	Production	Consumption	Export	Import	Waste
	Rice	196.54	416.99	0.00	220.45	0.00
	Maize	26.15	26.15	0.00	0.00	0.00
	Finger millets (Mandia)	98.01	98.01	0.00	0.00	0.00
	Redgram legumes (Kandul)	26.41	26.41	0.00	0.00	0.00
	Jhudanga	1.24	1.24	0.00	0.00	0.00
	Kating	0.00	0.00	0.00	0.00	0.00
	Vegetables	4.17	1.88	3.04	0.75	0.00
	Banana	3.04	0.00	3.04	0.00	0.00
Food	Jack fruit	2.94	0.38	1.07	0.00	1.49
	Papaya	0.40	0.40	0.00	0.00	0.00
	Dry food	0.00	1.03	0.00	1.03	0.00
	Others (potato, etc.)	0.00	0.24	0.00	0.24	0.00
	Meat	1.89	1.89	0.00	0.00	0.00
	Dry fish (marine)	0.00	1.46	0.00	1.46	0.00
	Sugar	0.00	0.50	0.00	0.50	0.00
	Molasses	0.00	0.47	0.00	0.47	0.00
	Tobacco	0.63	0.63	0.00	0.00	0.00

Original Article

Sub total		361.42	577.68	7.15	224.90	1.49
Oil seed	Niger	17.64	17.64	0.00	0.00	0.00
Sub total		17.64	17.64	0.00	0.00	0.00
Minor Forest products	Tamarind fruits	0.62	0.62	0.00	0.00	0.00
	Bamboo (weight)	298.29	285.25	13.04	0.00	0.00
	Leafy vegetables	0.37	0.09	0.28	0.00	0.00
	Small timber/poles (in weight)	159.09	159.09	0.00	0.00	0.00
	Broom grass	4.92	0.98	3.94	0.00	0.00
Sub total		463.29	446.03	17.26	0.00	0.00
Fodder	Paddy straw	156.63	147.68	0.00	0.00	8.94
	Other straw	150.86	128.23	0.00	0.00	22.63
	Bran/husk (legumes and millets)	94.23	94.23	0.00	0.00	0.00
	Crop residues	107.72	107.72	0.00	0.00	0.00
Sub total		509.43	477.86	0.00	0.00	31.57
Fuel	Firewood/ fuelwood (tons)	3885.00	3127.50	757.50	0.00	0.00
	Kerosene (tons)	0.00	60.48	0.00	60.48	0.00
	Dung (tons/year)	281.09	233.31	0.00	0.00	47.78
	Agriculture residue	70.18	49.61	0.00	0.00	20.57
Sub total		4236.27	3470.91	757.50	60.48	68.35
Grand total		5588.05	4990.12	781.91	285.38	101.41

Original Article

Table 11. Energy flow in Bhaliabhatta village ecosystem (GJ $year^{-1}$).

Production, consumption, export, import and waste of energy in Bhaliabhatta village ecosystem (GJ $year^{-1}$)

Sources	Items	Production	Consumption	Export	Import	Waste
	Rice	84.27	194.50	0.00	110.22	0.00
	Maize	14.68	14.68	0.00	0.00	0.00
	Finger millets (Mandia)	37.32	37.32	0.00	0.00	0.00
	Redgram legumes (Kandul)	13.09	11.36	1.73	0.00	0.00
	Jhudanga	0.78	0.78	0.00	0.00	0.00
	Vegetables	2.04	1.25	1.19	0.40	0.00
	Banana	1.74	0.00	1.74	0.00	0.00
	Jack fruit	0.96	0.21	0.00	0.00	0.75
Food						
	Papaya	0.34	0.34	0.00	0.00	0.00
	Dry food	0.00	0.56	0.00	0.56	0.00
	Others (potato, etc.)	0.00	0.16	0.00	0.16	0.00
	Meat	0.79	0.79	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.85	0.00	0.85	0.00
	Sugar	0.00	0.33	0.00	0.33	0.00
	Molasses	0.00	0.33	0.00	0.33	0.00
	Tobacco	0.16	0.16	0.00	0.00	0.00
Sub total		156.17	263.62	4.67	112.85	0.75
Oil seed	Niger	8.88	8.88	0.00	0.00	0.00
Sub total		8.88	8.88	0.00	0.00	0.00
	Tamarind fruits	0.37	0.37	0.00	0.00	0.00

Original Article

	Bamboo (weight)	138.55	138.55	0.00	0.00	0.00
Minor forest products	Leafy vegetables	0.21	0.05	0.16	0.00	0.00
	Small timber/poles (weight)	89.44	89.44	0.00	0.00	0.00
	Broom grass	4.10	0.82	3.28	0.00	0.00
Subtotal		232.67	229.23	3.44	0.00	0.00
	Paddy straw	44.92	42.12	0.00	0.00	2.80
	Other straw	66.95	59.08	0.00	0.00	7.87
Fodder						
	Bran/husk (legumes and millets)	27.06	27.06	0.00	0.00	0.00
	Crop residues	56.36	54.53	0.00	0.00	1.83
Subtotal		195.29	182.80	0.00	0.00	12.50
	Firewood/ fuelwood (tons)	1597.50	1252.50	345.00	0.00	0.00
	Kerosene (tons)	0.00	30.24	0.00	30.24	0.00
Fuel						
	Dung (tons/year)	180.03	145.79	0.00	0.00	34.24
	Agriculture residue	37.16	29.89	0.00	0.00	7.27
Subtotal		1814.69	1458.43	345.00	30.24	41.51
Grand total		2407.70	2142.95	353.10	143.09	54.75

Table 12. Energy flow in D. Kumbharbadi village ecosystem (GJ $year^{-1}$).

Production, consumption, export, import and waste of energy in D. Kumbharbadi village ecosystem (GJ year-1)

Sources	**Items**	**Production**	**Consumption**	**Export**	**Import**	**Waste**

	Rice	243.56	402.77	159.21	0.00	0.00
	Maize	14.85	14.85	0.00	0.00	0.00
	Finger millets (Mandia)	60.42	60.42	0.00	0.00	0.00
	Redgram legumes (Kandul)	12.40	12.40	0.00	0.00	0.00
	Jhudanga	0.85	0.85	0.00	0.00	0.00
	Vegetables	3.26	1.84	1.89	0.47	0.00
	Banana	4.69	0.00	4.69	0.00	0.00
	Jack fruit	3.37	0.34	1.49	0.00	1.54
Food	Papaya	1.02	1.02	0.00	0.00	0.00
	Dry food	0.00	0.61	0.00	0.61	0.00
	Others (potato, etc.)	0.00	0.13	0.00	0.13	0.00
	Meat	1.87	1.87	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.81	0.00	0.81	0.00
	Sugar	0.00	0.67	0.00	0.67	0.00
	Molasses	0.00	0.33	0.00	0.33	0.00
	Tobacco	0.95	0.95	0.00	0.00	0.00
Sub total		347.21	499.85	167.29	3.03	1.54
Oil seed	Niger	11.88	11.88	0.00	0.00	0.00
Sub total		11.88	11.88	0.00	0.00	0.00
	Tamarind fruits	0.62	0.62	0.00	0.00	0.00
Minor Forest products	Bamboo (weight)	224.94	211.90	13.04	0.00	0.00
	Leafy vegetables	0.19	0.19	0.00	0.00	0.00
	Small timber/poles (in weight)	101.31	101.31	0.00	0.00	0.00
	Broom grass	3.28	0.82	2.46	0.00	0.00
Sub total		330.34	314.84	15.50	0.00	0.00

	Paddy straw	193.68	181.55	0.00	0.00	12.13
	Other straw	102.45	95.36	0.00	0.00	7.09
Fodder	Bran/husk (legumes and millets)	116.12	116.12	0.00	0.00	0.00
	Crop residues	92.09	15.21	0.00	0.00	76.88
Sub total		504.35	408.24	0.00	0.00	96.10
	Firewood/ fuelwood (tons)	2955.00	2377.50	577.50	0.00	0.00
	Kerosene (tons)	0.00	43.68	0.00	43.68	0.00
Fuel	Dung (tons/year)	193.81	181.70	0.00	0.00	12.11
	Agriculture residue	37.65	32.11	0.00	0.00	5.54
Sub total		3186.46	2634.98	577.50	43.68	17.65
Grand total		4380.24	3869.79	760.29	46.71	115.29

Table 13. Energy flow in Papikhunti village ecosystem (GJ year^{-1}).

Production, consumption, export, import and waste of energy in Papikhunti village ecosystem (GJ yr^{-1})

Sources	**Items**	**Production**	**Consumption**	**Export**	**Import**	**Waste**
	Rice	0.00	97.98	0.00	97.98	0.00
	Maize	10.97	10.97	0.00	0.00	0.00
	Finger millets (Mandia)	56.05	56.05	0.00	0.00	0.00
	Barnyard millets (Koshala)	73.14	73.14	0.00	0.00	0.00
	Redgram legumes (Kandul)	46.90	38.23	8.67	0.00	0.00
	Vegetables	8.42	2.32	6.47	0.37	0.00
	Banana	0.96	0.00	0.96	0.00	0.00
	Jack fruit	1.51	0.17	1.07	0.00	0.27
Food	Papaya	0.57	0.57	0.00	0.00	0.00
	Dry food	0.00	0.58	0.00	0.58	0.00

	Others (potato, etc.)	0.00	0.15	0.00	0.15	0.00
	Meat	0.77	0.77	0.00	0.00	0.00
	Dry fish (marine)	0.00	0.76	0.00	0.76	0.00
	Sugar	0.00	0.33	0.00	0.33	0.00
	Molasses	0.00	0.27	0.00	0.27	0.00
	Tobacco	0.32	0.32	0.00	0.00	0.00
Sub total		199.60	282.60	17.17	100.44	0.27
Oil seed	Niger	71.42	13.66	57.76	0.00	0.00
	Rasi	29.49	7.32	22.17	0.00	0.00
Sub total		100.90	20.97	79.93	0.00	0.00
Minor forest products	Tamarind fruits					
	Bamboo (weight)	0.37	0.37	0.00	0.00	0.00
	Leafy vegetables	122.25	122.25	0.00	0.00	0.00
	Small timber/poles (in	0.26	0.07	0.19	0.00	0.00
	weight)	79.15	79.15	0.00	0.00	0.00
	Broom grass	2.46	0.82	1.64	0.00	0.00
Sub total		204.49	202.66	1.83	0.00	0.00
	Other straw	64.65	49.78	0.00	0.00	14.87
Fodder	Crop residues	139.63	139.63	0.00	0.00	0.00
Sub total		204.28	189.41	0.00	0.00	14.87
Fuel	Firewood/ fuelwood (tons)	1522.50	1222.50	300.00	0.00	0.00
	Kerosene (tons)	0.00	26.88	0.00	26.88	0.00
	Dung (tons/year)	242.29	211.22	0.00	0.00	31.07
	Agriculture residue	117.52	114.25	0.00	0.00	3.27
Sub total		1882.31	1574.85	300.00	26.88	34.34
Grand total		2591.59	2270.49	398.93	127.32	49.48

Table 14. Total production and consumption of energy in villages (GJ year^{-1}).

Uphill village	Patlamba	Rodanga	Khajuri	Gortali
Production	6000.37	9852.59	10249.25	6407.36
Consumption	2248.64	5911.51	8356.48	5319.67
Savings	3751.73	3941.08	1892.77	1087.69
Foothill village	Majhihalma	Bhaliabhatta	D.Kumbharbadi	Papikhunti
Production	5795.33	2722.74	4380.24	2591.59
Consumption	5168.72	2438.60	3869.79	2270.49
Savings	626.61	284.14	510.45	321.10

Table 15. Export-import of energy for food, minor forest products, fodder, fuel and ratio in villages.

	Energy value in GJ			
Uphill village	Patlamba	Rodanga	Khajuri	Gortali
Export	3715.84	4001.95	1758.75	1080.8
Import	175.56	585.09	484.34	309.41
Ratio	21.16	6.83	3.63	3.49
Foothill village	Majhihalma	Bhaliabhatta	D. Kumbharbadi	Papikhunti
Export	781.91	353.10	760.2	398.93
Import	285.38	143.09	46.71	127.32
Ratio	2.73	2.46	16.27	3.13

Analysis of variance (ANOVA) for the energy production, consumption of different sources such as food, minor forest products (MFP), fodder and fuel in different villages showed that there is a significant difference between these values. The differences in energy production and consumption in food, minor forest products (MFP), fodder and fuel among different villages are also significant. ANOVA for the energy export and import of different energy types such as food, MFP, fodder and fuel at the 8 villages reveals that there is a significant difference in different sources while there is no significant difference between these sources among the villages. ANOVA for the waste of different categories of energy at 8 villages shows that there is a significant difference in waste of energy among food, MFP, fodder and fuel at the 8 different villages while there is no significant difference in waste energy among the villages (Table 16). The 3-way ANOVA data for cultivation type (podu, mid hill, home garden and valley cultivation), site and category (grains, straw and residue) showed F values for these three factors that show a highly significant difference (Table 17). This indicates that there is a distinct difference in the cultivation types, segregation of energy content and among villages of the Niyamgiri hill ecosystem.

Conclusion

The data on energy dynamics in these villages highlight the significant role of biomass from the forest in the material flow of the village ecosystem. This is evident through the participation of minor forest products, firewood, small timber (poles) and bamboo. The village ecosystems are heavily dependent on biomass fuel and fodder from the nearby forest. The import and export figures for different items suggest that the tribal village ecosystem is open and partially independent. The Niyamgiri forest, covering a vast area of 496.59 km^2, is undulating with hills, stream sides and located far away from each other. Although man-animal conflicts are not frequent, the presence of herbivores and occasional wild elephants can lead to crop damage. However, these issues are managed by the tribal community, and compensation is provided for damages as per government provisions.

Recommendations

On the basis of the studies on subsistence economy and interaction between agriculture and ecology of villages, it was observed that the village community of Niyamgiri hills depend on nature assets intensely. One of the conservation priorities should be to improve the economic conditions of tribal society in order to protect structural and functional characters of the Niyamgiri forest for sustainable productivity. Food being the basic necessity of the society needs inter-disciplinary approach for sustainable production. Agriculture, horticulture and forest department must work with convergence to ensure sustainability of these traditional villages. Improvement of animal resources has great potential to meet socioeconomic needs. Storage and value addition of agriculture and horticulture products will boost up village economy while reducing dependency on natural resources from forests for human livelihood.

Table 16. F and p- values of analysis of variance (ANOVA) for different energy sources (food, MFP, fodder, fuel) at study villages.

Energy parameter	Source of variation	F	P-value
Energy production (GJ/year)	Energy sources	34.49	0.001
	Villages (sites)	2.72	0.05
Energy consumption (GJ/year)	Energy sources	38.948	0.001
	Villages (sites)	2.457	0.05
Energy export (GJ/year)	Energy sources	7.887	0.001 NS
	Villages (sites)	1.57	
Energy import (GJ/year)	Energy sources	13.338	0.001
	Villages (sites)	1.279	NS
Waste (GJ/year)	Energy sources	7.478	0.001
	Villages (sites)	1.119	NS

Table 17. Three-way analysis of variance (ANOVA) between cultivation type (Podu, mid hill, home garden and valley cultivation), site and category (grains, straw residue).

Source	DF	SS	MS	F	P
Total	95	38961.8			
Treatment	54	36277.2	671.8	10.26	0.001
Cultivation type	3	24084.6	8028	122.64	0.001
Site (village)	7	3840.3	548.61	8.38	0.001

Category	2	3974.6	1987.3	30.36	0.001
Interaction	42	4377.7	104.23	1.6	0.005
Error	41	2684.6	65.46		

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Altieri MA (1980). Agro ecology: The science of sustainable Agriculture Westview Press, Boulder, CO USA.

Altieri MA (1995). Agroecology: The science of sustainable agriculture. Boulder: Westview Press.

Anderson A (1990). Alternatives to Deforestation: Steps Towards Sustainable Use of Amazon. Rain Forests. Columbia University Press, New York.

Brooker RW, Bennett AE, Cong WF, Daniel TJ, George TS, Hallett PD (2014). Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytologist 206:107-117. Conway GR (1997). The doubly green revolution. Penguin Books London.

Dash SS, Misra MK (2001). Studies on Hill Agro-ecosystem of three tribal villages on the Eastern Ghats of Orissa, India. Agriculture, Ecosystem and Environment 86:287-302.

Drinkwater LE, Snapp SS (2007). Nutrients in agroecosystem: rethinking the management paradigm. Advances in Agronomy 92:163-186.

Food and Agriculture Organization (FAO) (1993). Shifting Cultivars of Indonesia: Marauders or Managers of the Forest. Community Forestry Case Study series, FAO, Rome. 119 p.

Forest Survey of India (FSI) (2021). India State of Forest Report 2021. Forest Survey of India, Dehradun, India. 587 p.

Gangwar AK, Ramakrishnan PS (1987). Agriculture and animal husbandry among the Sulungs and Nishis of Arunachal Pradesh. SOC Action 37:345-372.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010). Food security: The challenge of feeding 9 billion people, Science 327(5967):812-818.

Goodman GT (1987). Biomass energy in developing countries: problem and challenges.

Gopalan C, Rama Sastri BV, Balasubramaniam SC (1978). Nutritive Value of India Foods. National Institute of Nutrition, ICMR, Hyderabad.

Jarvis DI, Brown ADH, Imbruce V, Ochoa J, Sadiki M, Karamura E, Trutmann P, Finckh MR (2007). Managing crop disease in traditional agro ecosystem, Colombia University Press, New York, USA. pp. 292-319.

Lambin EF, Meyfroidt TP (2011). Global land use change, economic globalization- and the looming land scarcity, Proceeding of the National Academy of Science 108(9):3465-3472.

Loucks OL, Dalesio A (1975). Energy flow and human adaptation: A summary of ecosystem studies. The institute of Ecology, Madison, Wisconsin.

Millennium Ecosystem Assessment (2005). Ecosystem and Human Well-being: Synthesis. A report of the Millennium Ecosystem Assessment. World Resources Institute and Island Press, Washington D.C., USA.

Mishra BK, Hegde MS, Subramanian DK, Narendra Prasad S (1983). Studies on village ecosystems of north Kanara district of Karnataka. Technical report 12, Centre for Ecological Sciences, Indian Institute of Science Bangalore, India.

Maikhuri RK, Rao KS, Saxena KG (2004). Bio prospecting of wild edibles for rural development in Central Himalaya. Mountain Research and Development 24:110-113.

Mitchell R (1979). An analysis of Indian Agro-ecosystems, Interpreters, New Delhi.

Moench M (1989). Forest degradation and the structure of biomass utilization in Himalayan Foothills village. Environmental Conservation 16:137146.

Mulumba JW, Nankya R, Kiwuka C, De Santis P, Fadda C, Jarvis ID (2012). A risk-minimizing argument for traditional crop diversity use to reduce pest and disease damage in agricultural ecosystems of Uganda. Agriculture, Ecosystems and Environment 157:70-86.

Nautiyal S, Maikhuri RK, Rao KS, Semwal RL, Saxena KG (2003). Agroecosystem function around a Himalayan Biosphere Reserve. Journal of Environmental Systems 29:71-100.

Nayak SP, Nisanka SK, Mishra MK (1993). Biomass and energy dynamics in a tribal village ecosystem of Orissa India. Biomass and Bio-energy 4:23-34.

Nelson GC (2005). Drivers of ecosystem change: summary chapter, In: Hassan, R. Scholes, R. and Ash N. (eds) (2005). World Resources Institute and Island Press, Washington, DC, USA. pp. 73-76. Netting R (1993). Smallholders, householders. Stanford University Press Stanford California.

Nisanka SK, Mishra M (1989). Ecological study of an Indian Village Ecosystems: Energetics Biomass 1449-4565/90.

Nisanka SK, Mishra MK (1990). Ecological study of an Indian village ecosystem. Biomass production and consumption. Biomass 23:117136.

Nisanka SK, Misra MK, Sahu NC (1992). Economics of fuel energy in an Indian village ecosystem. Bioresource Technology 39(3):249-261. Pandey UMA, Singh JS (1984). Energetics of Hill Agro-ecosystems: A Case Study from Central Himalaya Agricultural Systems 13(2):83-95.

Phalan B, Onial M, Balmford A, Green RE (2011). Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. Science 333(6047):1289-1291. Pimentel D, Pimentel M (1979). Food, Energy and Society. Edward Arnold, London.

Rao KS, Maikhuri RK, Nautiyal S, Saxena KG (2003). Local people's knowledge aptitude and perceptions of planning and management issues in Nanda Devi Biosphere Reserve, India. Environmental Management 31(2):168-181.

Reddy AKN (1982). Rural energy consumption pattern – A field study – Biomass 2(4):255-286.

Robertson, GP, Paul EA, Harwood RR (2000). Greenhouse gases in intensive agriculture: contribution of individual gases to the radiative forcing of the atmosphere. Sciences 289(5486):1922-1925.

Sahoo HP (1993). Ecological studies on Indian Coastal village ecosystem Ph.D. Thesis, Berhampur University, Berhampur, India.

Sahoo HP, Mishra MK (1992). Ecological study of an Indian coastal village ecosystem. International Journal of Environmental Studies 39(4):257-266.

Schenldar RR (1995). Government and the Economy on the Amazon Frontier. World Bank, Washington, D.C.

Scurlock JMO, Hall DO (1990). The contribution of biomass to global energy use 1987. Biomass 21(1):75-81.

Singh VP, Singh JS (1992). Energetics and environmental costs of agriculture in a dry tropical region of India. Environmental Management 16:495-503.

Tomich TP, Brodt S, Ferris H, Galt R, Horwath WR, Kebreab E (2011). Agroecology: A review from a global charge perspective. Annual Review of Environment and Resources 36:193-222.

Tscharntke T, Khein AM, Kruess A, Steffen-Dewenter I, Thies C (2005). Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecology Letters 8:857-874.

Van der Maarel E (1993). Some remarks on disturbances and its relations to diversity and stability. Journal of Vegetation Science 4:733-736.

Williams RH (1985). Potential role of bio-energy in an energy efficient world. Ambio 14(4/5):201-209.