Title: ***Sustainable Land Use and Water Management in Mountain Ecosystem: Case Study of a Watershed in the Indian Himalayas***

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Land Use and Water Management in a Sustainable Network Society

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Abstract: The paper proposes to analyze the problem of choice of land use and technology for forest regeneration with minimum adverse impacts on the ecosystem. As the nature of the problem of such choice of land use and technology would depend upon the local characteristic of the ecosystem we propose to take up a case study through developing a model of analysis at the watershed level economies in the Himalayan mountains. The issue of choice, which is involved in the analysis of the particular case study, is supposed to yield valuable analytical and policy insights, which can be generalized for rural situations with similar geomorphic, eco-regional and agro-climatic conditions.

This work develops a quantitative optimization framework of analysis using the mathematical tool of linear programming for structuring and articulating the problem of choice. The modeling framework essentially focuses on optimal use of land and energy resources in two alternate exercises of net revenue maximization and cost minimization. The range of options that the model would attempt to articulate through the case study would cover the following aspects: (a) Use of land for agriculture, pasture and forestry including conversion from one use to the other. (b) Choice of technology as determined by (i) seed (ii) water (iii) fertilizer (iv) animal energy and (vi) human labour. (c) Choices in commercial and non commercial fuel use for household and agriculture in the rural system taking account of the nexus between food and energy linked with the pattern of land use. The scope of analysis also covers the implication of choice in terms of the following impact on the global and local ecosystem. (a) Emissions in the form of carbon di oxide and methane from agricultural process and fuel use. (b) Soil erosion.

While the model based case study work out the total water requirement for any land use pattern it has not considered any choice of source of water use, as there was no effective choice for the case study considered. The constraint of water availability has been taken into account to show how it drives the choice of technology and land use. A dynamic analysis of the problem would have been insightful however due to paucity of time series data on certain variables dynamic analysis wouldn't be possible, instead the attempt here is to determine an alternate combination of inputs and land use pattern in an optimization exercise for a given year under different technologies. The attempt is to identify cost effective technologies, optimal land use pattern, input combinations and prescribe policies for adopting these technologies and help in attaining the optimal land use and input combinations for various outputs such that the impact on ecosystem is minimal.

Keywords: Land Use, Sustainable Development, Mountain Ecosystem
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Economic development whether in upland or in plains has involved continuous interaction between the efforts of human beings to improve their material well-being, and the processes of nature. While the environmental challenges of development have induced many scientific discoveries and innovations in technology and social organization which significantly contributed in relaxing the constraints of carrying capacity of nature, the efforts of development have sometimes resulted in environmental degradation, economic and social stagnation, and human suffering. The latter has been caused partly by inefficient resource allocation and management and partly by explicit neglect of environmental concerns in the development process.

The character of this ecological degradation, however, differs with the state of development of an economy, and its ecological and socio-cultural setting. The overpopulated, poverty-stricken, bio-mass-based developing economies face environmental problems due to both the pressure of population and the unsustainable use of resources. The latter arises from the failure of social and economic institutions to resolve the problems of property rights, externalities, and those of income and asset distribution. The mountain areas in developing countries like India have their further specificities in respect of environmental problems of degradation or conservation due to the feature of verticality in physiography, resource richness and biodiversity and ecological fragility. The economy of mountain society revolves around the primary economic activities like agriculture, animal husbandry, forestry etc. The conventional industrial development becomes often infeasible as a development strategy in the mountain due to high cost energy and transport for carrying raw material and products to production site or markets. The higher costs on these accounts are likely to offset the higher labour productivity of industry vis – a – vis the primary sector. As all primary activity involve land use and as land use pattern has also intimate connection with the character of ecology of the concerned geographic area or region the issue of land use becomes crucial in any discussion of environmental sustainability of the development process in the mountains.

This paper discusses the problem of sustainable development in mountains in India, particularly in the Himalayan Region and presents a case study of land use and energy planning in a micro watershed to illustrate how the ecological conservation can be enhanced by rational land use with choice of appropriate technology even if we ignore the value of ecological services rendered due to use of land as forests. The case study uses linear programming framework for static allocation of land resource in alternative uses as well as alternative use of technologies. The paper also discusses the policy implications of such case study in respect of strategy of mountain development in India.

2. Sustainable Developmental Problems in Mountains

The environmental resource base of mountain is characterized by its steep gradient and verticality of physiography, mountain heights play crucial role in the climatic conditions of the tropical region of India and determine the character of regional distribution of the global hydrological cycle. The glaciers and watersheds of the mountain regions have been the sources of innumerable water streams which form into rivers and major flows of surface water in the lower level of plain terrain. The slopes of the hills have mostly been covered by forests which often contain rich biodiversity of plants and animal organisms. It is however also true that such forest eco-system as it exists today is very often fragile in many parts of the mountainous region in India. Fragility of such ecosystem has been due to the extremely leached and poorly developed soil condition of the forest ecosystem of the concerned region. The soil has become acidic at many places due to leaching caused by heavy rainfall in mountains and the vegetation there has got quite inadequate nutrient support. With nutrient deficiency of the thin layer of top soil, the nutrients release by the decomposition of the dense biomass of the surface vegetation has to be matched by rapid uptake of the forest ecosystem through a tight recycling of the nutrients that takes place through the surface root mats of the plantations, without allowing the nutrients to be leached into the mineral elements of the soil. If such a forest is ever disturbed, the topsoil layer, which is already leached, would erode very easily. With inadequate soil to hold vegetation and no forest to protect soil due to deforestation, ecosystem would degenerate to one of rocks denuded of forests with arrested grassy patches replacing the earlier vegetation. This has been a historical reality at many mountainous regions in India.

The mountain regions with forest resources in India have been inhabited by human population in scattered settlements. In the pre-capitalist stages of development of our economy, the traditional societies in these settlements on the hills had evolved their livelihood in tune with the ecological processes of the region. The people of such societies were endowed with traditional ecological knowledge which was based on human trial and errors of experiments and their insights based on such empiricism. Such societies evolved customs and strong religious cum cultural norms which guided the use of natural resources of the mountains' ecosystems and mostly ensured the combining of conservation of ecological resources and maintenance of livelihood. The pattern of land use, the cropping pattern in agriculture and other practices relating to primary activities in most of the tribal societies of the hills took account of the consideration of nutrient recycling and soil conservation (e.g. the practice of crop rotation and leaving the plot fallow for some time as followed in the hilly regions, etc.).

The growth of human population and human activities interfered with the ecosystem's functioning in the mountains of the developing countries like India. The growth of developmental activities of the plains had also its impact on the mountains which had been the source of roundwood, minerals etc. The growth of population of the Himalayan Regions in the past two decades has been higher than that of the plains due to various socio-economic and demographic factors. The economy of the hills in India has been an agro-pastoral and forestry based one. With the growth of human population and livestock, there has been change in land use pattern, forest land being converted into agricultural land or forest land being overused for animal grazing – both causing degradation of land. The increasing dependence on rainfed agriculture on slopes or terrace cultivation by removing forests to meet the increasing food requirement of a growing population have caused soil erosion in the hills. The same pressure of food requirement has reduced the full cycle time of use of a plot of land in shifting cultivation causing nutrient loss of soil over time as the nutrients cannot often be replenished within such short time frame through biogeochemical cycles. Such pressure for food security led to violation of cultural norms given by many of the traditional ecological knowledge. On the other hand, the use of chemical fertilizer not only creates scarcity of water resource in hills, but often affects the biological activities in soil causing problems of nutrients inadequacy. In more recent times the compulsion of securing livelihood for a rapidly growing population has also put pressure on the forests. The requirement of more agricultural land has caused the depletion of forests and an expansion of rain-fed agriculture on the slopes of the hills. Rain-fed agriculture on the slopes of the hills has extremely low productivity and prone to high degree of soil erosion. About 90 percent of the total cultivated area in the mid hills of the Western Himalayas is under rain-fed agriculture. The model that follows tries to identify technology that will reduce this category of land and allow its conversion to a more sustainable use which can halt the process of soil erosion.

The growing population of livestock which is an important source of livelihood for the hill people also creates pressure on the ecosystem. Cattle, goats and sheep constitute important livestock wealth in the Western and Central Himalayas while pigs and poultry in the Eastern Himalayas; yaks are reared in Alpine areas. Land holdings being very small, livestock supplement the income of poor households and are considered to constitute capital asset. Animal dung is used as fertilizer. The energy requirement for land preparation and transportation in agriculture is entirely met from bullock power. Overgrazing and open grazing by livestock are often argued as a major causes of poor regeneration and degradations of forest and pasture land causing both physical and chemical degradation of soil in the hills. The removal of green foliage along with the roots of grasses caused by overgrazing often results in soil erosion as well as chemical degradation of soil. Overgrazing is due to lack of exclusive fodder crops farming in the mountains. Mismanagement of forests contributes to overgrazing and forest degradation. The reserved forests are managed by the forest department mainly to earn revenue. Gradually these forests have been converted into *Chir* pine and *Deodar* forests which have high commercial value, broad-leafed spices like *Oak, Kafal, Sandan, Bauhinia, Ficus, Hatab* etc which supplied fodder and fuel-wood have gradually dwindled. The pressure of fuel-wood and fodder consequently fell on the civil and community forests, which started shrinking. Efforts of diffusing grazing pressure on land in local animal husbandry systems do exit. The animals are sent to high altitudes for grazing in the summer months, a significant portion of fodder is obtained from crop residue. Nevertheless a trend of increasing pressure of livestock on forests is obvious. The model framework of land use that has been outlined in the following section takes into account the fodder requirement and the possibility of animal energy utilization for economic activities

The conventional capitalist development in the economy of the plain has also contributed to deforestation in the mountains because of the harvesting of round woods for commercial purpose at a rate higher than the rate of regeneration. The pressure of population has also caused high rate of harvesting of fuel wood for the purpose of energy supply. Besides, the quarrying activities of mineral deposits in hills have inevitably caused destruction of forest. The change in land use as induced by these factors has vastly compounded the problem of ecological degradation of the mountains leading to loss of soil, moisture and immensely valuable biodiversity

With the removal of forest and soil erosion, the water holding capacity of the soil and vegetation system of the mountains declines resulting in loss of rechargeable ground water, soil and moisture and surface run off which is not harvestable for local use in the mountains. With declining capacity of the soil vegetation system to hold water and growing population, the water balance at the hilltops has worsened over time in India. This has caused rise in time and labor for water collection as the distance of the point of collection has increased with water stores.

In Himalayas, degradation of forest cover gives rise to many other problems, soil erosion, disruption of hydrological cycle, increased overland flow, siltation of river beds, floods and water logging in the plains, loss of biological diversity, scarcity of forest resources like fuel-wood and fodder, overburdening of women with more work and resultant deterioration of child care are associated with deforestation. The implementation of the Forest Conservation Act in 1980 is an attempt to halt the process of deforestation in the hills. One of the major concerns of the land use model is to examine to what extent the conversion of land use would be warranted for increasing area under forests and striking a new ecobalance.

Energy is demanded in the hills is for cooking lighting and heating in the household, the possibility of irrigated cultivation of fruit trees, herbs and medicinal plant and vegetables may be considered in small areas of land may be considered if electricity is available for such activities.. It is estimated that about 11 lakh (10^5) million cubic meter of water flow every year down the Himalayas. Technological interventions at micro-level have the capability of producing hydro electricity in abundance. The use of hydro electricity for household purposes would reduce the pressure on forests for fuelwood. Decentralized and small scale management systems involving active people's participation and adapted to mountain constraints appear more suitable particularly for meeting the minimum needs of marginal areas. The Himalayas offers a potential of generating 28,000 MW of electricity. Flow of water as a result of gravitational force provides immense scope for power generation and improving upon the efficiency of cultivation systems of the region.

The energy requirement for cooking and space heating is met from the fuelwood collected from local forests. This increase pressure on forests causes it to shrink; the depletion of forest causes womenfolk to spend more time in fuelwood collection. Technological options for supply of energy for agriculture and household needs have to be assessed and explored. Fuel options which are economically efficient and ecologically sound needs to be identified. Energy options with least intensity of carbon-di-oxide emission would be suitable for fragile mountain ecosystem. In the model that has been framed the impact of a micro hydel power system on land use has been estimated.

There has been a steady growth in population in the Himalayas in this century. According to the latest Census in 2001, the growth rate of population in the hill states is higher than the average growth rate of the country. Himachal Pradesh and the hill districts of Uttar Pradesh show one of the lowest growth rates in the hill region. In Chamoli and Almora districts of Uttar Pradesh, where the growth rate is the lowest, the population is likely to be 2.63 times the present population in 60 years, the doubling period of population would be around 30 years. For other regions of the Himalayas the doubling period would be even less. There may be an argument that population increase does not necessarily lead to ecological degradation. There is no statistically significant relation between population growth and decrease in forest cover (Rao and Saxena,1994). Nagaland, a state with highest population growth show the lowest extent of deforestation while Manipur, Meghalaya and Tripura with similar growth rate in population differ considerably with respect to deforestation (Forest Survey of India, 1995). Nevertheless, lack of evidence of positive changes in response to population growth supports the view that population growth increase pressure on the ecosystem. The land use model tries to incorporate the growing population pressure in terms of basic need and food demand.

With deforestation, unsustainable agriculture and their consequent impact on soil, water, vegetation cover and biodiversity, the carrying capacity of the mountain ecosystems in terms of the size of the life support to the human and livestock population has declined over time. With growing population, such development of ecological degradation has often led to out migration of able-bodied male population of working age group to the plains for earning livelihood and sending remittances to the hills. In many places, the sex-age composition and occupational pattern are found as per some of the primary surveys to be such that the population is dominated by dependents consisting of the old and the children who are being looked after by the adult women staying back in the villages. Most of the activities relating to agriculture for growing food and collecting fuel wood and water which are all quite physically strenuous are being carried out by the women. This adds a gender dimension to the pattern of livelihood and quality of life in the hills and raises concern for well being of the women population due to stress caused by dwindling life support as provided by ecosystem

3. A Case Study of Optimal Land Use in Mountains:

The discussion of the preceding section points to the importance of pattern of land use in determining both ecological sustainability of an ecosystem and the economic well-being of the people inhabiting the concerned region. We submit below an optimization model of land use for the Hawalbag watershed region and summarize here the results in order to illustrate the real extent of conflict between developmental needs and environmental concern. The analysis based on the model essentially focuses on the existing patterns of land use and its connectivity with the various economic activities in the watershed region and compares it with the optimal pattern of land use for the region. The comparison points to the potential of combining efficient choice of technology and land use with environmental conservation in such watershed region in the mountains. It illustrates how it is sometimes the inefficient land use and technological choice in the hills which cause both loss of conventional economic value as well as ecological resources like top soil, air quality, etc. The optimization model (linear programming type) articulates the problem of all kinds of choices in the use of land, technology and natural resources for alternative purposes with the objective of net revenue maximization from the major primary activities of the watershed economy subject to meeting the basic need of food and energy for human beings as well as livestock, the latter being an important resource providing support to the mountain economic system. The surplus land that remains after meeting the basic needs of the watershed would be devoted to the most market value adding use among the various options as per the logic of optimization. The model considers the bounds of the availability of land of various categories and water resources as given. To be more precise, the range of options that the model would attempt to articulate in the case study would cover the following aspects:

(a) Use of land for agriculture with or without irrigation, pasture and forestry after allowing for conversion from one use to the other. Choice of cropping pattern along with seasonality has been explicitly considered in the model.

(b) Choice of technology as determined by the use of (i) seed (ii) water (iii) organic and chemical fertilizer (iv) animal energy for land preparation and rural transportation and (vi) human labor.

(c) Choices of fuel among commercial and noncommercial energy resource options for household and agriculture in the rural system taking account of the nexus between food, fodder, fertilizer and energy as linked with the pattern of land use. (For example, crop waste of agriculture can be used either as fodder or biomass fuel or compost fertilizer. Biomass crop waste fuel is a substitute of commercial and noncommercial energy forms. Dung of livestock can again be used alternatively for fertilizer, energy; etc livestock also provides energy for agriculture and rural transportation.

The scope of analysis also covers the implication of choice in terms of the following impact on the global and local ecosystem.

(a) Soil erosion.

(b) Emissions in the form of carbon dioxide from agricultural process and land use.

The Hawalbag watershed – the chosen study area is in the central Himalayas between altitude 1000-2000 meters where human activities have been widespread in terms of population growth, deforestation, extension of agriculture, growth in livestock and demand for energy resources. The micro watershed on the bank of river Kosi called Hawalbag has been chosen as the area of study spreading over an area of 6088 acres and containing human population of 4780 and livestock population of 3729 distributed in 15 villages.

The assumptions and detailed statement of the mathematical model is given in Appendix. The model has been estimated on the basis of data obtained from primary survey sources conducted by the authors in the Hawalbag area. The exogenous variables of the model describe the basic needs of the people in the concerned watershed region for a given year. The estimated model considers the economy of the watershed region to be representative one for illustrative purpose.

Results:

The major feature of the results of the model under reference on land use has been that out of 5802.36 acres of land use, the total mass of land for agriculture with irrigation and rainfed agriculture should be 410.15 acres and 20.85 acres respectively, as against 39.52 acres of existing net sown irrigated area and 2740.44 acres of net sown rain fed agriculture. (See Tables 1 to 4) The land under pasture should also decrease from the existing 1373.11 acres of use to 919.97 acres. The forestland under use should increase from the existing 1532.73 acres to 4451.36 acres of land. The optimization model results emphasize the economisation of land use under agriculture by shifting acreage from inefficient rain fed agriculture on slopes to irrigated agriculture with use of fertilizer or organic manure in valleys as far as possible. The pastureland use should also be kept at the minimum by efficient resource use and all surplus land after meeting the need of food and fodder should be transferred for use in forestry. It is the net value addition of products of forestry which makes forestry an attractive option purely on economic ground of surplus maximization. Even without taking account of eco-service value rendered by forests, the revenue maximization objective would warrant transfer of land from agricultural and pastoral use to forest use subject to the constraints of meeting the basic needs of food and fodder within the watershed. The present use of larger acreage under agriculture is indicative of the inefficiency of land use in rainfed agriculture and also possibly of anxiety of mountain people of holding as much foodgrain stock as possible for reasons of food security.

Sensitivity analysis of land allocation for a percentage change in food demand is given in Table 1. Increase in the share of rainfed agricultural land would be higher for increase in food demand since the extra land requirement would entirely come from the rainfed agricultural land. Increased demand for food would put pressure on pastureland and forestland which would be set to decline gradually.

As per the results of the model, water constraint for agriculture in the watershed is not yet conspicuous. Due to lack of irrigation facilities the potential of water is not fully realized. Water potential essentially permits the changed pattern of land use for agriculture. However, the maximum potential of sustainable water use permits 410 acres of irrigation. The optimal land use pattern has however warranted full use of this potential for production of foodgrains and vegetables, making the water constraint binding and requiring small acreage of land use under rainfed conditions. An installed capacity of 10-20 Kw hydel plant and 6 engines of 20 hp will be required for this purpose. If two 10 Kw or one 20 Kw of hydel plant is installed, the total cost of irrigation would be Rs. 65038. The initial investment requirement per 10 Kw plant would be Rs. 2.8 lakh (90-91 prices). The cost of 6 engines would be Rs. 1 lakh (90-91 prices); 415 acres of irrigated agriculture will be able to meet the entire demand for food grain of the watershed. The other agricultural input that has a significant role to play in changing land use patterns is fertilizer. The results of the model indicate that there is sufficient scope of increasing productivity in agriculture by better management of local resources like dung and other biomass based manure. A technological intervention for anaerobic digestion of dung would greatly increase the fertility potential of locally available organic manure. About 43 percent of the dung generated will optimally flow to the anaerobic digester to meet the entire requirement for N, P and K of the watershed. The requirement of yield increase for supporting the basic needs of a rapidly growing population can be met by the better management of organic manure. Further, the anaerobic technology will initiate substitution away from chemical fertilizer which would make agriculture better environmentally reproducible.

On the livestock management, the optimization exercise allows crop waste, fodder grown in fallow lands and grazing in pasture and old forests as the major sources of fodder. Crop residue can contribute 21.78% according to the net revenue maximizing exercise. Fodder from fallow land, which is left fallow after three seasons of cultivation, contributes marginally i.e. 0.11% of total fodder requirement. A major share of fodder comes from grazing pasture. In this particular exercise it has been assumed that the livestock does not graze in the new forest area since allowing grazing while regenerating of forests will decrease the chances of survival of the plants. Grazing may be allowed in a full-grown forest. About 2556 acres of forest will be required to sustain the livestock population if grazing in full grown forests is allowed, in that case no pasture land would be required. So, as forests start regenerating, pastureland may be gradually brought under forests. A sensitivity analysis indicates that 1 percent increase in fodder demand would increase allocations to pasture land by 1.28 percent (See Table 5). The results point to the better opportunity use of crop waste for fodder than for other uses like compost fertilizer or for cooking fuel.

On the front of inanimate energy, the requirement of such energy for cooking, lighting and space heating should be ideally supplied, as per the results of the model, by electricity from micro-hydel units which can be set up to tap the hydro energy potential of the region. In any situation of scarcity of electric power because of inadequate investment to utilize such potential, it is the LPG gas and soft coke which would be the next best option for cost economisation for cooking and space heating respectively. Dung is to be mainly used for organic fertilizer. The optimization model warrants a part of it to be used in anaerobic digester to produce slurry for fertilizer.

The environmental impact of the change in land use and related activity pattern as per the net revenue optimization model would be favourable in respect of topsoil loss, carbon emission and carbon sequestration. Total soil erosion will be reduced by 77% according to the changed land use pattern as per the model. A large amount of agricultural land located on the slopes can be released for afforestation by increasing area under cultivation in the valley land. The carbon emission due to energy consumption would also be drastically reduced by the utilization the hydro-potential of the region. This would of course require mobilization of capital fund and institutional arrangement for implementation of power projects.

Finally, transfer of land to forest use will facilitate substantial carbon sequestration in the region by substantive amount, the net sequestered amount being 5466 tonnes of carbon as per the optimal solution. Afforestation would also have favourable impact on employment situation due to expansion of forestry-based activities. However, such land use change in favour of forests would also demand appropriate institutional arrangement to be in place.

4 Model of Sustainable Development in the Mountains

In the light of the case study referred to above, it is important to note that environmental conservation of resources is intimately linked with the pattern of land use and technology in the mountains. It is also interesting to note that profit or net revenue maximizing allocation of resources in terms of land use goes often along with environmental conservation of resources like top soil, water resource, etc. It is in fact the choice of land use along with associated economic activities in the hill which is the crucial factor in characterizing the developmental process in mountains. What should then be the model of development for the mountains?

In view of the fragility of the ecosystem of the mountains in general, it is of prime importance that a development programme of the hills should minimize the interference with the ecosystems' functioning and stability. It is also important to take advantage of traditional ecological knowledge of the mountain societies by incorporating them in our body of scientific knowledge. This would permit better achievement of resource conservation through choice of appropriate technology based on such knowledge and livelihood practices.

In terms of sectoral strategy of development, the reference to the case study suggests that we depend on forestry and livestock raising mainly for livelihood in the hills. The agriculture should be confined mainly to valleys, except for such plantations which can be grown on gradient without degradation of soil-water system. This would not necessarily cause deficit of foodgrains. There may be deficit however in some cereals, pulses, etc. in the mountains. This deficit needs to be imported from the plains. While mountains provide ecological subsidy to the plains through the major flows of surface water and forest resources, the plains need to supply in return agricultural products, particularly food grains and other industrial goods to ensure life support on the hills. The conventional model of industrialization is thus of no relevance in mountains because of the high energy, transport and construction costs involved. The latter would in fact more than offset the advantage of higher labour productivity in industrial activities in comparison with primary activities due to the scope of division of labour offered by the former. The exception would be in agro-based food processing and plantation industries like tea or coffee or medicinal plants, honey, etc. in the hills. This would in fact involve less of material import from outside the hill for necessary processing unlike as in the case of mineral or other material based processing or other manufacturing industries.

The model of development of hills really needs to be oriented directly towards the concerns for human development subject to the constraints of the fragility of the mountain ecosystem. This, of course, would require as a basic precondition, the stabilization of population and removal of poverty. The former would require appropriate policies for population control through reproductive health care, education, and upgradation of social status of women so that the micro behavioral pattern as reflected in the choice of family size and fertility rate and the macro level concern for population stabilization may converge.

The removal of poverty, on the other hand, has to be achieved through ecologically sustainable livelihood – mainly through primary activities of forestry and livestock raising, limited agriculture, selected agro based food and plantation industries, tertiary activities in the service sector like eco-tourism (including transport, hotels and restaurants), education, health care, energy and water supply, etc. The earnings from these would continue to be supplemented by the remittances of the emigrants. Within the service sector it may be noted that the nonconventional decentralized technologies of renewable energy like micro-hydel, wind energy, biomass based power etc. would be competitive with conventional commercial energy like thermal grid power supplied from the plains to the hills. The organization of water and energy supplies with the help of modern environmentally sustainable technology is of crucial importance from the point of view combining the improvement of quality of life (particularly of women), with the provision of some sources of income to the people engaged in such activities. The tourism, on the other hand, needs to be regulated to ensure that the consumption wastes generated by this activity does not degrade the mountain environment. The development of hills can also include diversification into knowledge based service activities in the mountains whose output can be delivered through modern communication system at low cost. All these would, however, also require the development of the infrastructure of road, transport, telecommunication and electric power. The major challenge lies in finding strategies and technologies of development of the infrastructural constructs in the hills with least impact of ecological damage. One major trade off involved in any infrastructure development is the ecological damage caused by construction activities which enhance the vulnerability of ecosystem in the hills.

5.Conclusion

To sum up the consideration of sustainability of resource regeneration in the mountains restricts somewhat the scope of resource or technology substitution as well as product-mix because of the fragility of the ecosystem and very tight resource balance condition. This would permit only human activities such as forestry, limited agriculture, livestock raising, selective plantation and agro-forestry based industries and services like eco-tourism, education, health service, transport and communication as outlined above. The fragility of the ecosystem, high value of biodiversity and nonmarket ecoservices provided by the mountain ecosystems and the high cost of transport in hills constrain the income generation process in many places. The out migration of people would therefore be inevitable and the receipts from remittances will have to supplement local income generation in the hills in future too.

In respect of choice of economic activities, investment projects for development or development policies, what is important is both efficient choice of technology from the overall point of view of resource economisation as well as careful consideration of environmental or ecological costs and benefits in addition to the conventional developmental ones. The latter is important because of the ecological fragility and sensitivity of mountain ecosystem to human interference. The monetisation of such valuation of environmental benefits or costs is also crucial for our assessment of overall social cost-benefit of any choice of action or policy in mountains. In view of the site and ecological resource specificity of most of development related issues in the hills and the diversity of ecological resources as well as socio-cultural condition in the hills, it is important to carry out a wide range of case studies of valuation of the natural environment in the hills to develop insights in the economics of sustainable development for hills. For any development policy or project initiative application of the theory of such valuation to test whether the genuine value of policy change or investment is nonnegative, is necessary for ensuring the condition of sustainability. The latter requires as already noted that the value of the stock of wealth of the mountain society should be non-declining. In these valuations the central concepts of theory of valuation in economics are quite applicable. The unique non-sustainable role of most of the environmental resources, fragility of ecosystem and irreversibility of environmental damages are likely to very often result in a dominant share of change in the value of natural capital in the total wealth of a mountain socio-economic system.

As the constraints of nature are often likely to be binding in models of mountain development, interdisciplinarity would be important in the analysis of case studies of mountain development problems. Besides, the institutional issues are also intimately related with any model of sustainable use of natural resource and environment in the mountains. In mountain societies, market penetration has either destroyed the ecological sustainability or has been limited in many parts of such economy or society in which socio-cultural linkage with ecological processes has been strong. Given the socio-economic conditions in mountain societies, the models of sustainable mountain development as outlined above would be better operational through people's participation in a cooperative mode of development than in any market driven institutional regime subject to environmental regulation. Such institutional arrangement would greatly facilitate the use of traditional ecological knowledge for development purpose for removing poverty along with conserving environmental resources.

It may however also be noted in conclusion that while the role of interdisciplinarity in case studies of sustainable development would often be very important, this need not mean any radical departure from the basic conceptual framework of economics for the dealing with issues of valuation for policy analysis of sustainable development for mountains economies. It is admitted that the analysis of environment related problems in any region should take account not only of the limits of nature in decisions of economic choice, but should also analyze the impact of economic choices on ecology and take account of the feedback effect of ecological changes on the economic system to understand the dynamics of long run processes of economy, society and the nature. As institutions, society and culture would also importantly matter in all these interactive processes in hills or plains, the newly emerging ecological economics seeks to develop concepts and methodology needed to take account of interdisciplinarities. This however does not mean that the conceptual framework of the conventional economics dealing with theory of choice and valuation is of no relevance in the construct of analysis of such ecology related sustainable development issues. What is important is to choose an appropriate ethical theory of intergenerational and intergenerational equity on the one hand and ascertain the domain of substitutability among the alternative types of capital and natural resources and the boundary conditions of ecological limits on the other, which can adequately take care of environmental or ecological concerns in defining the problems of sustainable development. The principles of economics need to be put at central place to develop the conceptual framework of analysis of most of the sustainable development issues of real life including those of the mountains while the interdisciplinarity would enter more importantly in the analysis of the case studies which are context specific. We can develop further understanding of these conceptual issues relating to methodology as we address real life problems of sustainable development particularly in ecologically vulnerable regions in mountains or plains.

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APPENDIX

Assumptions of the Model

(a) The model developed here assumes a simple rural economy with three competing land use activities, that of agriculture, livestock and forestry. This assumption is quite realistic in the context of a rural economy since these activities predominantly use local resources and have a significant impact on the ecosystem. Within agriculture, the options of rainfed and irrigated agriculture have been considered in respect of choice of technology. Cropping pattern has also been considered as matters of choice in land use for Khariff season and Rabi season separately. In other words seasonality is built in the characterization of land use making it season wise explicit.

(b) Agricultural output has been assumed to be a linear function of area cultivated. This is a very simplified way of explaining relationship between output and scale of operation. Such a model would be relevant for regions where land holding sizes are more or less uniform. Considering that the model is used in the case studies where land holding sizes are almost similar this assumption will not make any misrepresentation. The limitation of fixed technology implied by fixed coefficient of input and output has been partially overcome by conceiving two major technologies in agriculture i.e. irrigated and rainfed. Rainfed technology implies traditional methods of cultivation. Irrigated technology implies use of irrigation, high yielding variety seeds and enhanced fertilizer consumption. Mechanization of agricultural operations has not been considered since the model is relevant for regions that have small land holdings and cultivation is done predominantly by family labour. Mechanization will not be feasible due to lack of capital and low opportunity cost of labour. The model assumes that family labour is compensated according to the prevailing wage rate in order to arrive at the estimate of net revenue.

(c) Livestock size has been assumed to be given. The focus of the model is to ensure fodder availability for the livestock population while ensuring minimum impact on ecosystem. Animal energy use has been considered as the only source of energy for land preparation, while both animal energy and human labor are to provide energy for local rural transportation.

(d) For the purpose of computing revenue coefficients a full-grown forest has been assumed. It is also assumed that forests have a specific life period.

(e) Seasonal fluctuation in energy demand has not been considered explicitly since all energy resources considered except electricity can be stocked. Hence seasonal fluctuation in demand can be met from the stock. Local demand for grid electricity would be so less in comparison to installed capacity of the grid that fluctuations in local demand could be easily met by it. In the case of hydroelectricity from micro hydel power plants higher installed capacity has been inbuilt by assuming lower efficiency to account for seasonal fluctuations.

(f) A fixed coefficient energy value for all energy sources has been assumed.

(g) A fixed coefficient of emission for energy resources has been assumed; though under different physical condition of combustion, the rate of emission may vary.

(h) Soil erosion is assumed to be determined by the land use and gradient of land.

(i) For computation of net revenue of the region, revenue from land use activities and costs of land and energy use has been taken into account. The net revenue or economic surplus has been construed in such a manner to ensure economic viability of basic activities that has to function within the constraints of the ecosystem. A positive value of net revenue would ensure economic viability of land and energy use activities. Computation of total cost takes into account only costs related to land use and energy use since these are primary activities that causes an impact on the ecosystem.

(j) It is assumed that people surviving at subsistence level and located in remote areas are governed by concern for food security and availability. Hence, they would ensure that the land they possess should ensure availability of foodgrains and fodder to the extent possible. In the framework developed, a food and fodder constraint has therefore been considered. However, the implications of not having the food and fodder constraint have also been discussed in the relevant case study.

3.2.4. Notations of the Model

(i) Indices

Index a : *Land Type (Given)*

Index i : *Land Type (Converted)*

1. Irrigated Land.
2. Rainfed Agricultural land.
3. Pasture Land.
4. Forest Land.
5. Area put to non-agricultural use.
6. Cultivable wasteland.
7. Uncultivable wasteland.
8. Fallow land.
9. Land under shrubs and miscellaneous trees.

Index j : *Crop Types*

Index s : *Season*

1. Kharif in irrigated agriculture.
2. Rabi in irrigated agriculture.
3. Karif in unirrigated agriculture.
4. Rabi in unirrigated agriculture.

Index k : *Animal Type*

1. Drought Animal
2. Milch Animal
3. Youngstock

Index m : *Water Source*

1. Springs /River
2. Well
3. Tanks
4. Groundwater

Index z : *Fertilizer Type*

1. Chemical Fertilizer
2. Organic Fertilizer
3. Bio - Fertilizer
4. Slurry

Index f : *Fuel Type*

1. Fuel Wood
2. Cowdung
3. Crop Residue
4. Animal Power
5. Kerosene
6. Diesel
7. Electricity
8. Biogas
9. Cooking gas (LPG)
10. Coal

Index g : *Gradient Class*

(ii) Variables :

L_{ai} - 'a'th type land converted to 'i'th type land

YL_i - Total land converted to 'i'th type

ZL_{ij}^s - Area of 'j'th crop grown in 's'th season in ‘i’th agricultural land.

x_{ij}^s - Output of 'j'th crop per unit area grown in 's'th season in 'i'th type land.

FN_Z - Wt. of nitrogenous fertilizer used from the 'z'th source (Chemical, Biofertilizer)

FK_Z - Wt. of Chemical potassium fertilizer used.

FP_Z - Wt. of Chemical phosphatic fertilizer used.

FT_Z - Wt. of Fertilizer used from 'z'th source (dung & slurry)

C_f - Amount of 'f'th fuel source used for cooking.

L_f - Amount of 'f'th fuel source used for lighting.

H_f - Amount of 'f'th fuel source used for space heating.

R_f - Amount of 'f'th fuel source used for irrigation.

C_B - Wt. of dung used for biogas plant.

EX - Household organic waste used in biogas plant.

CW_{fd} - Wt. of crop waste used as fodder.

AH - Animal hours available in transportation of grains.

MH - Man-hours available in transportation of grains.

Impact Variables :

TEC - Total Emission of Carbon.

CSQ - Total Amount of Carbon sequestered by weight.

TSR - Total Weight of Soil Erosion

(iii) Coefficients :

γ_{ij}^{s} - Productivity per unit area of the 'j'th crop grown in 's'th season on 'i'th land

W_{ij}^{s} - Water requirement per unit area of the 'j'th crop grown in 's'th season on 'i'th land.

nf_{ij}^{s} - Nitrogenous fertilizer requirement per unit of 'i'th land growing 'j'th type crop in 's'th season.

nf_{Z} - Nitrogenous content per unit weight of 'z'th fertilizer source.

kf_{ij}^{s} - Potassium fertilizer requirement per unit of 'i'th land growing 'j'th type crop in 's'th season.

kf_{Z} - Potassium content per unit weight of 'z'th fertilizer source.

pf_{ij}^{s} - Phosphatic fertilizer requirement per unit of 'i'th land growing 'j'th type crop in 's'th season.

pf_{Z} - Phosphatic content per unit weight of 'z'th fertilizer source.

β_{i} - Green fodder availability from 'i'th type of land.

al_{k} - Fodder requirement per year per animal of 'k'th type.

AL_{k} - Total number of animal of 'k'th type.

am_{ij}^{s} - Animal energy requirement to plough a unit of land of 'i'th type growing 'j'th crop in 's'th season.

t_{S}^{1} - Time span (days) for land preparation in 's'th season.

t_{S}^{2} - Time span (days) for transportation in 's'th season.

t_{S}^{3} - Time span (days) for irrigation in 's'th season.

d_{T} - Average distance for transportation of grains.

an - Capacity of animal labour to carry a weight through a unit distance in an hour.

ah - Capacity of human labour to carry a weight through a unit distance in an hour.

h - Working hours of animal per day.

g_{k} - Weight of dung produced per 'k'th type of animal per year.

ec_{f} - Coefficient of useful energy for cooking from unit wt. of 'f'th energy source.

el_{f} - Coefficient of useful energy for lighting from unit wt. of 'f'th energy source.

r_{f} - Amount of land irrigated by a unit wt. of 'f'th energy source.

ϕ_{i} - Fuelwood available per unit of 'i'th land type.

cw_{j} - Crop residue per unit of output of 'j'th crop.

n_{1} - Amount of biogas generated per unit of excreta and dung.

n_{2} - Amount of slurry generated per unit of excreta and dung.

EC_{f} - Emission of carbon by weight from unit weight the 'f'th fuel source.

SQ - Weight of carbon sequestered per unit area of forest land.

SR_{ig} - Weight of soil loss from unit area of 'i'th type of land in 'g' gradient class.

EMP_{ij}^{s} - Total number of mandays employed in growing 'j'th crop in 's'th season per unit area of 'i'th type of land.

Coefficients of cost and Revenue

CC_{ai} - Cost per unit of land converted from 'a'th type to 'i'th type.

CT_{ij}^{s} - Cost of cultivation per unit of 'i'th type of land growing 'j'th crop in 's'th season

CT_{i} - Cost of raising one unit of 'i'th type of land.

CS_{3} - Total cost of pastures and forest.

CX_{4} - Total cost of cooking energy

CX_{5} - Total cost of lighting energy

CS_{1} - Total conversion cost of land

CX_{1} - Cost of cultivation (excluding irrigation and fertilizer cost)

CX_{2} - Total fertilizer cost

CX_{3} - Total irrigation cost

CS_{2} - Total agricultural cost

CS_{6} - Total cost of heating energy

CS_{4} - Total energy cost

CS_{5} - Transportation cost

PN_{Z} - Cost of one unit of nitrogenous fertilizer of the 'z'th source.

PK_{Z} - Cost of one unit of potassium fertilizer of the 'z'th source.

PP_{Z} - Cost of one unit of phosphatic fertilizer of the 'z'th source.

PC_{f} - Cost per unit of 'f'th energy source for cooking.

RC_{f} - End use cost per unit of the 'f'th fuel source for cooking.

PL_{f} - Cost per unit of the 'f'th energy source for lighting.

RL_{f} - End use cost per unit of the 'f'th energy source for lighting.

PH_{f} - Cost per unit of 'f'th fuel source for heating.

RH_{f} - End use cost per unit of 'f'th energy source for heating.

PR_{f} - Cost per unit of 'f'th energy source for irrigation.

RR_{f} - End use cost per unit of h 'f'th energy source for irrigation.

P_{AH} - Cost per unit of animal energy for transportation.

P_{MH} - Cost per unit of labour for transportation.

V_{ij}^{s} - Revenue per unit of 'i'th land growing 'j'th crop in 's'th seasons.

V_{i} - Revenue per unit of 'i'th land.

(iv) Demand and Supply Constraints:

TL - Total land availability.

X_{ij}^{s} - Demand for 'j'th crop grown in 's'th season in 'i'th land type.

W_{m}^{s} - Total water availability from the 'm'th source in the 's'th season.

W^{s} - Total water availability in the 's'th season.

NF - Total annual demand for nitrogenous fertilizer.

KF - Total annual demand for potassium fertilizer.

PF - Total annual demand for phosphatic fertilizer.

AL_{k} - Total animal of 'k'th type.

T_{s} - Total number of days in a season.

CE - Total annual requirement of cooking energy.

LE - Total annual requirement of light energy.

HE - Total annual requirement of heat energy.

3.5 The Model

Objective Functions :
Two optimization exercises may be carried out. Maximization of net revenue would imply

$$\text{Max} : \sum_{i=1}^{4} V_i - \sum_{X=1}^{5} CS_X$$

In the case studies that follow both these exercises have been carried out using Linear Interactive Data Optimizer (LINDO) software. The optimization model outlined above is the basic structure, it can be suitably amended to solve alternate/partial exercises, such exercises wherever required has been carried out and discussed in the results of the model in the following chapters.

Coefficients of Revenue :

Total Revenue ($\sum V_i$) is given by

$$\sum_{i=1}^{4} V_i = \sum_{i=1,2} V_{ij}^s + \sum_{i=3,4} V_i$$

Coefficients Of Cost :

(A) ***Conversion Costs*** **:**

There is a cost associated with conversion of the 'a'th type of land to 'i'th type (L_{ai}). Let the cost coefficient per unit land for conversion from 'a'th type to the 'i'th type be CC_{ai} . Total conversion cost will be

$$CS_1 = \sum CC_{ai}.L_{ai}$$

where	a	=	1,2,3,4,6,7,8,9
	i	=	1,2,3,4

(B) ***Cost Of Cultivation*** **:**

Let CT_{ij}^s be the coefficient of cost of seeds, pesticide and labour in the cultivation of the 'i'th land growing 'j'th crop in 's'th season. Total cost CX_1 is given by

$$CX_1 = \sum CT_{ij}^s.ZL_{ij}^s$$

Where	s	=	1,2 for i = 1
	s	=	3,4 for i = 2
	i	=	1,2
	j	=	1........J

Fertilizer and irrigation costs are accounted separately, it does not enter into CT_{ij}^s . This formulation was essential to allow for the choice of the least cost fertilizer and energy options. This also implies that land use decisions based on increased productively due to higher fertilizer use is ruled out.

(C) ***Fertilizer Cost*** **:**

Let PN_Z, PK_Z and PP_Z be the price of one unit of nitrogen, potassium and phosphorus form the 'z'th source. PT_2 is the price of one unit by weight of cowdung (FT_2). Total cost (CX_2) can be represented as

$$CX_2 = \sum_{Z=1,3} PN_Z.FN_Z + PK_Z.FK_Z + PP_Z.FP_Z + PT_Z.FT_Z$$

Slurry (FT_4) is assumed to be cost less since it is a by-product of biogas plant.

(D) Irrigation Cost :

Two types of costs are involved (a) Fixed cost which includes cost of capital equipment like pump sets and other construction work (b) variable cost like energy cost. The former may be included in cost of conversion; here we take into account only energy cost so that least cost energy option may be chosen for irrigation. Let PR_f be the cost of one unit of 'f'th energy source and RR_f be the end use cost per unit of 'f'th energy source.

$$CX_3 = \sum_f (PR_f + RR_f).r_f.R_f$$

f = 4, 6, 7, 8

Total Agricultural cost (CS_2) is given by

$$CS_2 = CX_1 + CX_2 + CX_3$$

(E) *Cost of Pastures and Forest* :

Let CT_1 be the coefficient of cost of raising an acre of forest and pasture land. Total cost of forest and pasture land (CS_3) is given by :

$$CS_3 = \sum_{i=3,4} CT_i . YL_i$$

(F) *Energy Cost* :

(i) *Cost of cooking energy*

$$CX_4 = \sum_f (PC_f + RC_f).ec_f.C_f$$

Where f = 1, 2, 3, 5, 6, 7, 8, 9, 10

(ii) *Cost of lighting energy*

$$CX_5 = \sum_f (PL_f + RL_f).el_f.L_f$$

Where f = 5, 7, 8

(iii) *Cost of heating energy* :

$$CX_6 = \sum_f (PH_f + RH_f).H_f$$

Where f = 1, 2, 3, 7, 10

Total energy cost (CS_4) is given by

$$CS_4 = CX_4 + CX_5 + CX_6$$

***(G) Transportation Cost* :**

$$CS_5 = P_{AH}.AH + P_{MH}MH$$

Total cost of land use, energy use and transportation activities would be $\sum CS_X$ where,

$$\sum_{X=1}^{5} CS_X = CS_1 + CS_2 + CS_3 + CS_4 + CS_5$$

3.5.1 Land Utilisation

We have the following classification of land type

$$\text{Total Land (TL)} = \sum_{a=1}^{9} L_a \qquad (3.1)$$

3.5.2 Conversion Activities

let L_{ai} represent land conversion from '*a*'th type to '*i*'th type. Total land converted to '*i*'th has to be less than total available land of '*a*'th type. This can be written as

$$\sum_i L_{ai} \le \sum L_a \qquad (3.2)$$

Where

a = 1,2,3,4,6,7,8,9

i = 1,2,3,4

Total land converted to '*i*'th type, denoted by YL_i may be obtained by formulating the above equation as

$$\sum_a L_{ai} \ge \sum_i YL_i \qquad (3.3)$$

Where a = 1,2,3,4,6,7,8,9

i = 1,2,3,4

Total land converted to '*i*'th type YL_i has to be less than total initial land of '*a*'th type available for conversion to '*i*'th type i.e. L_{ai}

Land category 5, put to non-agricultural use, mainly consisting of residential dwellings, paths, places of worship and funeral ground is assumed to be constant since requirement of land for these purposes are not likely to change. It is also assumed that no land gets converted to land category 6,7,8,9. The practice of leaving land fallow to regain its productivity is not followed in this region. The implication of leaving land fallow with respect to gain in productivity of land / output or cultivating some superior variety strains of crops that require higher fertility of soil is not available. Hence, land conversion to fallow has not been considered.

3.5.3 Agricultural Activities

Agricultural activities occupy land type YL_1 and YL_2. Let land category 1 be cultivated in seasons (s) 1 and 2 and category 2 in seasons 3 & 4. We define ZL_i^s as 'i'th land cultivated in 's'th season such that

$$ZL_i^s \leq YL_i \tag{3.4}$$

i = 1, 2
s = 1, 2 for i = 1
s = 3, 4 for i = 2

$\sum ZL_i^s$ is the gross cropped area. Let there be j crops being cultivated. The above equation would become.

$$\sum_j ZL_{ij}^s \leq ZL_i^s \tag{3.5}$$

Where i = 1, 2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1........J

We express output in terms of area and productivity. We get

$$x_{ij}^s \leq \gamma_{ij}^s ZL_{ij}^s \tag{3.6}$$

Where i = 1, 2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1........J

x_{ij}^s denotes output of 'j'th crop 'i'th land is 's'th season.

γ_{ij}^s denotes productivity of the same output. $\sum x_{ij}^s$ is the gross agricultural output.

3.5.4 Food Balance

$$X_{ij}^s \leq x_{ij}^s \tag{3.7}$$

Where i = 1,2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1......Jl

Here it is assumed that out of j crops being cultivated Jl crops are foodgrains.

To allow for imports this equation may be amended as $X_{ij}^s \leq x_{ij}^s + I_j$ where I_j denotes the quantum of import of the 'j'th crop. The value of import has to be correspondingly subtracted from the objective function if it is to be determined whether import will be preferred to local cultivation of a given crop.

3.5.5 Water Balance

$$w_{ij}^s . ZL_{ij}^s \leq W^s \tag{3.8}$$

Where i = 1
s = 1,2
j = 1,....J

Water maybe available from 'm'th source

$$\sum_m W_m^s \geq W^s \tag{3.9}$$

where m = 1,2,3,4
s = 1,2

W_m^s denotes water available from the 'm'th source in the 's'th season, W^S denotes total water requirement for the season.

3.5.6 Fertilizer Balance

(i) Nitrogenous Fertilizer

$$\sum_s \sum_i \sum_j nf_{ij}^s .ZL_{ij}^s \leq NF \tag{3.10}$$

Where i = 1,2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1......J

The supply comes from the above four sources. The total supply has to be greater than the total demand (NF). It can be stated as

$$\sum_{z=1,3} nf_z FN_z + \sum_{z=2,4} nf_z .FT_z \geq NF \tag{3.11}$$

FN_1 and FN_3 denote the weight of chemical fertilizer and biofertilizer respectively, while, FT_2 and FT_4 stands for organic fertilizer and slurry. Thus formulation was necessitated because of inseparability of nitrogen, potassium and phospate in organic fertilizer and slurry.

(ii) Potassic Fertilizer

Similarly for potassium fertililzer we have

$$\sum_s \sum_i \sum_j kf_{ij}^s ZL_{ij}^s \leq KF \tag{3.12}$$

Where i = 1,2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1......J

The supply comes from chemical fertilizer, cowdung and slurry, it has to be greater than total demand (KF). It can be stated as

$$\sum_{z=1} kf_1 .FK_1 + \sum_{z=2,4} kf_z .FT_z \geq KF \tag{3.13}$$

FK_1 denotes weight of potassium fertilizer, FT_2 and FT_4 stands for cowdung and slurry.

(iii) Phosphatic Fertilizer

For the Phosphatic fertilizer we have

$$\sum_s \sum_i \sum_j pf_{ij}^s .ZL_{ij}^s \leq PF \tag{3.14}$$

Where i = 1,2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1......J

The supply of phosphatic fertilizer may be represented as

$$\sum_{z=1} pf_1 .FP_1 + \sum_{z=2,4} pf_z .FT_z \geq PF \tag{3.15}$$

FP_1 denotes weight of phosphatic fertilizer. FT_2 and FT_4 stands for organic fertililzers (cowdung) and slurry respectively.

3.5.7 Livestock Activities

Fodder for livestock activity comes from YL_2, YL_3, YL_4 i.e. unirrigated agricultural land, pasture land and forest land. Crop residue (CW_{fd}) is also fed to livestock. The fodder equation can be expressed by

$$\sum_i \beta_i YL_i + CW_{fd} \geq \sum al_k AL_k \tag{3.16}$$

Where i = 2,3,4
k = 1,2,3

Livestock is an important source of animal energy in agricultural activity. Animal energy from draught animals (AL_1) is used for (a) land preparation (b) transportation (c) lift irrigation.

a) *Land preparation* :

$$\sum\sum am_{ij}^{s}.ZL_{ij}^{s} \leq AL_1.t_s^1.h \tag{3.17}$$

Where i = 1, 2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1........J

b) *Transportation* :

$$d_t\sum_i\sum_j X_{ij}^{s} \leq an.AH + ah.MH \tag{3.18}$$

Where i = 1,2
s = 1,2 for i = 1
s = 3,4 for i = 2
j = 1.........J

And $AH \leq AL_1.h.t_s^2$

'*ah*' denotes the capacity of human labour to carry a unit weight to a unit distance in an hour and MH is the required man-hour, t_s^2 denotes the time span of the agricultural season in number of days.

(c) *Lift Irrigation* :

$$\sum\sum ap_{ij}^{s}.ZL_{ij}^{s} \leq AL_1.h.t_s^3 \tag{3.19}$$

Where i = 1
s = 1,2
j = 1 ......J

Further it has to be ensured total days spent in land preparation, transportation and lift irrigation do not exceed total number of days in the season (T_s)

$$t_s^1 + t_s^2 + t_s^3 \leq T_s \tag{3.20}$$

Where s = 1,2,3,4

3.5.8 Energy Balance

(i) *Cooking Energy* :

$$CE \leq ec_f.C_f \tag{3.21}$$

Where f = 1,2,3,5,6,7,8,9,10

C_f and ec_f denotes total consumption and coefficient of useful heat energy of '*f*'th fuel option respectively.

(ii) *Lighting Energy* :

$$LE \leq \sum_f el_f.L_f \tag{3.22}$$

Where f = 5, 7, 8

L_f and el_f denotes total consumption and coefficient of useful light energy of '*f*' th fuel option respectively.

(iii) *Heating Energy* :

$$HE \leq \sum_f H_f \tag{3.23}$$

Where f = 1,2,3,5,7,10

H_f denotes total consumption of fuel option '*f*' for heating purpose.

(iv) *Irrigation* : Energy consumption in agriculture consist of irrigation, land preparation and transportation. We have considered each of these under livestock activities. Land preparation and transportation of foodgrains are dependent on animal power. We rule out the use of tractor in the subsistence agriculture. In the case of irrigation the geographical feature may or may not be suitable for use of animal power. Furthermore groundwater can not be lifted by using animal energy. Hence we take the case of irrigation allowing the use of diesel, electricity and biogas in addition to animal power.

Let r_f be the amount of land irrigated by one unit of the '*f*'th energy source, R_f is the total amount of '*f*'th fuel source

required for irrigation.
We represent this as

$$\sum_f r_f . R_f \geq \sum_i \sum_j ZL_{ij}^s \qquad (3.24)$$

Where

i	=	1	s	=	1, 2
	f	= 4, 6, 7, 8	j	=	1........J

3.5.9 Fuelwood Balance :

$$C_1 + H_1 \leq \sum_i \phi_i . YL_i \qquad (3.25)$$

where i = 3, 4

3.5.10 Dung Balance :

$$C_2 + H_2 + FT_2 + C_B \leq g_k . AL_k \qquad (3.26)$$

3.5.11 Crop Residue Balance :

$$CW_{fd} + C_3 + H_3 \leq \sum_j cw_j . x_j \qquad (3.27)$$

where j = 1.......J

3.5.12 Biogas Balance :

$$R_8 + C_8 + L_8 \leq n_1 (EX + C_B) \qquad (3.28)$$

3.5.13 Slurry Balance :

Slurry is a by-product of biogas. Slurry generated can be represented as

$$FT_4 \leq n_2 (EX + C_B) \qquad (3.29)$$

3.5.14 Impact On Ecosystem :

Emission **:** Two types of emission have been considered, the emission of carbon due to energy use and emission of methane (CH_4) from rice cultivation. Oxides of carbon and methane contribute to greenhouse effect and global warming. Let EC_f be the emission index (by weight) of carbon of the 'f'th fuel source. Total Emission of Carbon (TEC) is given by

$$TEC = \sum_{f=1}^{10} EC_f . (C_f + H_f + L_f) \qquad (3.30)$$

Carbon Sequestration :

Carbon may be sequestered in the forests. Let SQ be the weight of carbon sequestered per acre of forest. Total carbon sequestration (CSQ) will be given by

$$CSQ = SQ . YL_4 \qquad (3.31)$$

Soil Erosion :

Intensity of soil erosion depends on the use that land is put to and its gradient. Soil erosion index of Agricultural land. Pasture and forest may be computed in terms of weight of soil loss per unit of land, let SR_{ij} be the soil erosion index of the 'i'th type of land in the '*g*'th gradient. Total soil erosion (TSR) is given by

$$TSR = \sum_{j=1}^{4} SR_{ig} . YL_{ig} \qquad (3.32)$$

3.5.15 Employment :. Let EMP_{ij}^s be the total employment requirement of the 'j'th crop grown in 'i'th agricultural land in the 's'th season.

EMP_j denotes employment requirement of an unit of 'i'th type of non-agricultural land. Total employment (TMP) would be

$$TMP = \sum_{i=1,2} \sum_j \sum_s EMP_{ij}^s . ZL_{ij}^s + \sum_{i=3,4} EMP_i . YL_i \qquad (3.33)$$

3.5.16 Non-negativity Constrains :

All land use and energy use activities have to be non-negative. This may be represented by

$YL_i \geq 0$ (3.34) $L_f \geq 0$ (3.38) 3.34

$ZL_{ij}^s \geq 0$ (3.35) $H_f \geq 0$ (3.37) 3.35

$C_f \geq 0$ (3.36) $R_f \geq 0$ (3.39) 3.36

Annexure Tables

Table 1
Land Use Pattern in Hawalbag Micro Watershed

SL No.	Notation	Land-Use Type	Area in acres
1	L1	Net Sown Area (irrigated)	39.52
2	L2	Net Sown Area (rainfed)	2740.44
3	L3	Pasture Land	1373.11
4	L4	Forest Land	1532.73
5	L5	Non Agriculture Uses	272.81
6	L6	Cultivable Waste Land	17.87
7	L7	Uncultivable Waste Land	6.15
8	L8	Fallow Land	-
9	L9	Shrubs & Trees	107.47
		Total Land	6088.55

Table 2
Optimal Land Allocation for Agriculture

Land Type	***Seasons***	***Crops***	***Land Requirement*** (acres)
Irrigated	Kharif	Rice	253.778
Irrigated	Kharif	Vegetable	61.68
Irrigated	Rabi	Wheat	318.5
Irrigated	Rabi	Vegetable	26.75
Irrigated	Rabi	Mustard	12.8
Irrigated	Rabi	Potato	52.08
Rainfed	Kharif	Rice	10.42
Rainfed	Kharif	madua	10.42
Rainfed	Rabi	Wheat	10.42
Rainfed	Rabi	Potato	10.42
Rainfed	Rabi	Mustard	-

Table 3
Optimal Land Use Patterns

Land Type	Land Use Pattern Net Rev.Max Ex
Total Irrigated Agricultural Land	410.15
Total Rainfed Agricultural Land	20.85
Pasture Land	919.97
Forest Land	4451.36
Surplus Land	
Total Land	5802.36

Table 4
Land Conversion (acres)

Land Conversion	Net Rev . Max. Ex
Rainfed to irrigated agricultural land	370.63
Rainfed agricultural land to forest land	2349.41
Pasture land to forestland	453.14
Cultivable waste land to forest land	9.09
Land under trees and shrubs to forest land	107.47
Surplus Rainfed agricultural land	

Table 5
Sensitivity Analysis of Land Distribution
(Due to 1% increase food demand)

Rate of charge in land distribution (%)	Net. Rev. Max. Exercise
Total Agricultural Land.	1.85
Rainfed Agricultural Land	40
Pasture Land	-0.13
Forest Land	-0.15