

Studies on Resource Management for Sustainable Ecosystem of Eastern Himalaya

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ABSTRACT— *Soil, water and vegetation are three basic natural resources. Production, conservation, and sustainability of natural resources are constantly threatened by a possibility of improper human interventions and uses of the natural resources. The present study was conducted consecutively three year from March, 2010 to February, 2013 at Regional Research Station (Hill Zone) under the aegis of Uttar Banga Krishi Viswavidyalay, Kalimpong, with a view to find out the sustainable management of various natural resources for improved livelihood in Darjeeling –Sikkim Himalaya. Natural resource management specifically focuses on a scientific and technical understanding of resources and ecology and the life-supporting capacity of those resources. Our study revealed that farmer usually practice six category of practice for optimum utilization of available resource in the Darjeeling Himalaya. Educational qualification level of the farmers (n = 120) were maximum upto middle school and they got information related to various available natural resources from panchayat office and was followed by blocks level office. Further study at farm level revealed that farmers most often used farm/agriculture publication for getting information on agriculture and other available natural resource. Study revealed that the hill ecology faces degradation land and forest by overexploitation of available resources. This can be manage through some improved practices such as conservation tillage, agroforestry and maintain of soil fertility through improved available technology.*

Keywords—Biodiversity, Conservation, Darjeeling himalaya, Natural resources.

1. INTRODUCTION

Poor access to appropriate technologies due to difficult topographies and tough mountain conditions is one of the major causes of poverty, drudgery and natural resources degradation not only in the Darjeeling Himalaya, but also in other parts of the Eastern Himalaya also. However, Darjeeling Himalaya is fortunate to have still a pristine environment. Darjeeling and Sikkim hill, is a small geographical entity located in the Eastern Indian Himalayan mountain system (Mukherjee, 2013). Completely landlocked and criss-crossed by green valleys, high peaks and rippling rivers the region is bounded on the north by China (Tibetan Plateau), Bhutan and Tibetan Plateau on the east, Nepal on the west and the Darjeeling Hills of West Bengal on the south. The Darjeeling-Sikkim Himalaya has been identified as one of the 25 global hotspots in terms of biodiversity and its available natural resources. Its complex terrain system, high humidity, varied aspects, abruptness of altitudinal variation and use of different natural resources for crop production are a few important factors that contribute to the immense wealth of biological resources, and this way, Darjeeling biodiversity contributes significantly to the country's ecological heritage and to the global and national ecological balance. Soil, water and vegetation are three basic natural resources (Mukherjee, 2011). The survival of God's creation depends upon them and nature has provided them as assets to human beings. Natural resource management refers to the management of natural resources such as land, water, soil, plants and animals, with a particular focus on how management affects the quality of life for both present and future generations. The management of natural resources to meet people's requirements has been practised since the pre-vedic era. Farmers were ranked high in the social system and village management was in their hands. In order to manage land, water and vegetation, technical knowledge suitable to the specific conditions of a region is required. They gained this knowledge and developed skill through experience and learning by doing.

Over-exploitation of natural resources by growing population resulted in severe problems. Destruction of vegetation has resulted in land degradation, denudation, soil erosion, landslides, floods, drought and unbalanced ecosystems. A balanced ecosystem is an urgent need. In this direction, agroforestry coupled with some sound resource conservation techniques needs to be strengthened for long-term sustainable production and environmental conservations in fragile ecosystem which will contribute to improved food security and income generation for resource poor farmers and protect the environments (Mukherjee, 2012 a). Integrated farming system has emerged as a well accepted, single window, and sound strategy for harmonizing simultaneously joint management of land, water, vegetation, livestock, and human resources, The IFS developed for hill areas could reduce the risk of soil degradation, produce the soils productive

potential, and reduce the risks of environmental degradation and well being with the natural resource management approach. Biological control measures combining good agronomic and soil management practices are directed at selecting land uses that provide good protection of the soil from raindrop impact, increase surface depression storage and infiltration capacity of the soil to reduce the volume of runoff, improve soil aggregate stability to increase its resistance to erosion and increase the roughness of the soil surface to reduce the velocity of runoff. Mulch farming appears to be an effective conservation measure in all ecological regions especially when used with planted cover crops in eastern part of Himalaya. Mulch farming in combination with a no-tillage system has a wide application and is an effective conservation technique for grain crop production on a range of soils in this part of India. Ridging is widely practised and is effective in soil and water conservation, especially contour ridging is more effective. The use of terraces and contour bunds as physical protection measures is limited by the poor socio-economic conditions of farmers in Darjeeling Himalaya. Trees are traditionally part of Darjeeling-Sikkim Himalaya farming systems. Where properly integrated they can be an essential element in improved and more productive food crop systems. These hill people also have their own agricultural practices, crop varieties, and water harvesting practices. They have also evolved rich knowledge with respect to their fauna and their great medicinal value that are confined to the knowledge of the handful of the locals. However, rapid economic development, poor management and corruption have had a large destructive impact on the region's ecological systems and devastating effect on available natural resources. In the last 40 years ecosystems in the region have declined at twice the global average.

The Regional Research Station, Uttar Banga Krishi Viswavidyalaya, Kalimpong, involve in various activities in the rural areas of Darjeeling for the management of resources with people's participation. Over time the region has evolved various traditional knowledge pertaining to its rich natural resources and their practices. These practices have a strong base in the socio-religious system native to the region and have been evolved over 100s of years. The present investigation was the outcome of experience gained in the villages of Darjeeling Himalaya and the part of Sikkim region along with the farmer adoption perception. In contact with the farmers, traditional wisdom was documented along with present outcome of various field observation.

1.1 Background and objective

Darjeeling was basically a rural subsistence society till the 1950's. In absence of modern infrastructure, limited trade was conducted via bartering with Tibet, Bhutan and rest of the world. The forests surrounding the settlements were used to collect firewood (for cooking and warming), timber and bamboo (for construction material), herbs and medicinal plants (for traditional medicine), forest food (to fill the food gaps), irrigation water (for paddy cultivation), cattle grazing (for dairy products and meat) and many others. "For centuries, the people of Darjeeling hill have preserved their natural resources and lived in balance with nature. Ensuring the integrity of forests, rivers and soil was vital for the survival in the high valleys of the Darjeeling Himalayas. The relationship between the Nepalese people and the environment has been forged over centuries within moral, cultural and ecological boundaries. Respect for these boundaries was ensured historically through a set of formal and informal rules and norms. Traditional and local beliefs promoted the conservation of the environment, and key ecological areas were recognized as the abodes of gods, goddesses, protective deities and mountain, river, forest and underworld spirits. This traditional respect for the natural world ensured that Darjeeling emerged into the 20th century with an intact natural resource base." During the last four decades, an impressive development has taken place in Darjeeling hill. This development was to a large extent stimulated and determined by the intervention of Govt. and integrated effort of NGO with local people.

1.2 Problems and issues of the region

Trends reflecting exploitation of natural resources at rates much higher than those at which these resources get replenished, are presently evident all through the Darjeeling. The reasons and consequences of these trends are also well known. While dramatic increase in per capita resource demand is identified to be the basic cause of widening the gap between resource exploitation and replenishment in the affluent regions, population explosion is argued to be the strongest determinant of such trends in the developing and underdeveloped regions. Consequence of these trends appear as deterioration in environmental quality in terms of deforestation, poor biological productivity and utility potential, soil erosion, hydrological imbalances, flood and other natural hazards and socio-economic disparity. With increasing elevation the systems are characterised by i) lower rates of abiotic, biotic and cultural exchanges, ii) slower rate of growth, iii) slower aging and late maturity, iv) poorer reproductive efficiency, and v) higher resistance. Such areas exhibit less visible impact of environmental problems at present. However, the impact of natural hazards increases with increasing elevation. The important issue of Darjeeling Himalaya are:

- A realization of special consideration of the peculiarities of hilly terrain and hill societies in development policy formulation and planning process
- An appreciation of the values of hills in the maintenance of ecological balance, along with their long term economic values
- Preference to development programmes relying more on indigenous/local rather than external resources
- Emphasis on the area specific development programmes compatible to ecological and social specificities of an area, rather than a blanket plan for all hills

- A need for hastening the process of technology transfer
- Importance of long term studies for ecological and economic changes in time and interactions in space for a realistic understanding of the hill ecosystems
- Relevance of integrated management of natural resources and programme implementation in ecological units instead of administrative units.

2. METHODOLOGY

Keeping above all this issue in mind, participatory learning and sharing of knowledge was the method adopted during the present field-based programme on development of environmentally sound technologies together with capacity building of local people for natural resource management practices. The present study was conducted from March, 2010 to February, 2013 at Regional Research Station (Hill Zone) under the aegis of Uttar Banga Krishi Viswavidyalay, Kalimpong, with a view to find out the sustainable management of various natural resources for improved livelihood in Darjeeling –Sikkim Himalaya. Darjeeling district is triangular in shaped with 3254.7 sq. km., which is 3.68 percent of the total areas of West Bengal state. The hilly region covers 2320 sq. km. and the remaining 934.7sq.km of the area falls in the Terai and plains. The altitudinal variations of the district range from 150 m at Siliguri to 4036 m at Sandakphu-Phalut with a sharp physiographic. The intensive field survey was conducted in the entire Darjeeling and various part of Sikkim hills. Study area lies between 26^o31' – 27^o13' N latitudes and 87^o59'– 88^o53'E longitudes. Our work confined to Darjeeling, Kurseong and Kalimpong form and few pocket of adjoining Sikkim state. Area selected for this purposive study area mainly to obtained comprehensive information on various practices of natural resource management by the farmers and what improved method better for conservation of natural available resources in mountainous regions. Farmers were interviewed to obtain information on various practice follow to conserve natural resource, and this were further concluded with the scientific information and trial at Regional Research Farm at Kalimpong and Lava (Sherpa Gao). A total of 120 farmers including women were interviewed. For the study purpose the relevant socio-personal and field level primary data were collected from the five villages namely three villages from Kalimpong block I and two from Sukhiapokhri and Rimbhik, respectively in from Darjeeling district. These villages were selected purposively owing to their greater acquaintance and accessibility on the part of the investigator. One hundred twenty farmers were selected which had practice various natural available resources for their farming system and average land holding of 1.5 to 2 ha. Farmers were selected randomly following simple random sampling without replacement technique. All necessary information were collected through specially designed pretested schedule following personnel interviewed and by observing the existing land area for crop along with enterprise they have considered as the source of natural resource management. Simple tabular analysis was adopted for the interpretation. Further, individual contacts were made and questions were asked about traditional systems in the villages and how this helps to conserve environment. Representation of women among the farmers was also ensured. By means of informal interviews and interaction with old and young farmers and farm women, responses were recorded for critical analysis. Information was collected with respect to the social and historical perspective of the Darjeeling himalaya region, depletion of natural resources, methods of conservation, concept of water management, prediction and beliefs, and cultural education.

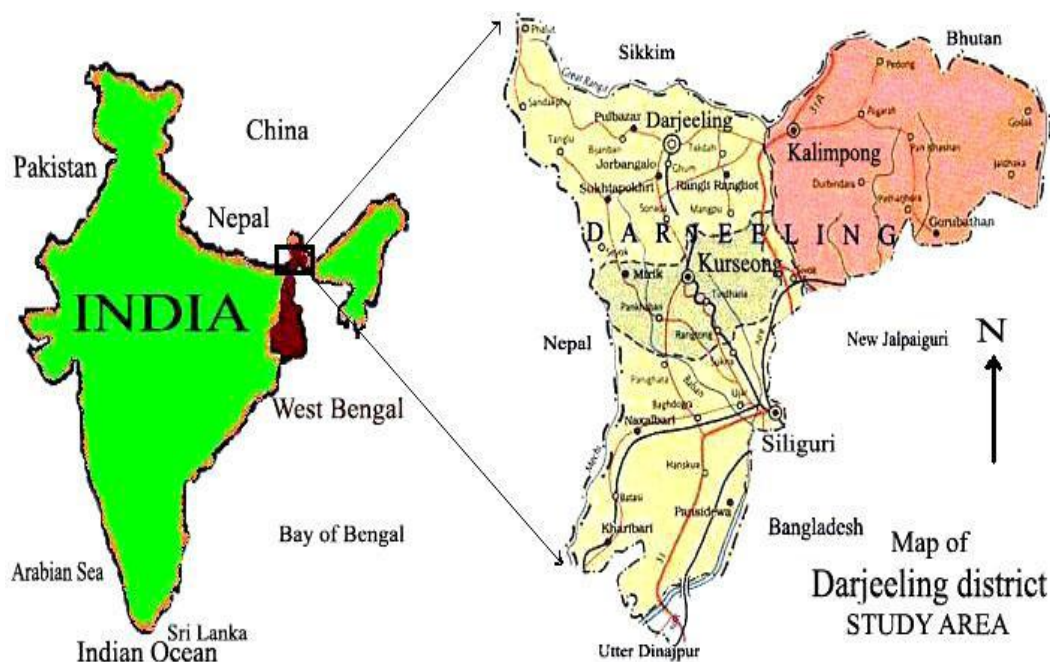


Fig. 1: Location of Darjeeling district (study area) of West Bengal, India

3. RESULTS AND DISCUSSION

The Darjeeling Himalaya is gifted with abundant natural resources. The resources can be grouped into biotic or abiotic, both of which can be renewable. Biotic resources include agriculture crops, fodder and forests. During the ancient period Darjeeling and Sikkim hills were full of dense forest and lush green vegetation. This part of Himalaya is the perennial source of water for rivers, streams and reservoirs. Undoubtedly, nature takes care of its resources through natural process over a period of time and maintains them. But ever-increasing population, developmental activities and technological modernisation have over-exploited available resources without taking into consideration the damage and consequences for coming generations. Vegetation plays an important role in protecting land and water. Our observation revealed that these resources are being depleted at an alarming rate because of human intervention. The downward rush of water has tremendous erosive force and moves millions of tonnes of fertile soil during the rainy season. It causes all types of erosion as well as devastating landslides in the Darjeeling hills. Developmental activities, construction of roads, extraction of building material and mining, etc., were a constant threat. Field observation and farmers' experiences over the years predict untimely and unprecedented rainfall with longer winter droughts. Consequently, these changes have resulted in reduced soil moisture for crops (e.g. large cardamom) and higher competition for water resources among users.

In this investigation, adaptation and utilization of available natural resources to day to day farming business and certain socio-personal characteristics like education qualification, cosmopolitanism and media exposure of the farmers were studied. Our study revealed that farmers usually practice six categories of practice for optimum utilization of available resource in the Darjeeling – Sikkim Himalaya (Table 1). Amongst various farmers under sampling, maximum percentage (25 %) follow crop under agroforestry system, where they took care of all available natural resources within their farm unit. Educational qualification level of the farmers were maximum upto middle school (21.66 % , Rank I) followed by madhyamik level (20.83%, Rank II) and minimum percentage of qualification level was above graduate level (0.81 % , Rank VI) (Table 2). The cosmopolitanism of the farmer's i.e. visit of the farmers to different places or offices in regular interval for their technical knowledge related to utilization of various available natural resources for their optimum utilization and other agricultural works related to their day to day activities (Table 3). Maximum number of farmer's visits panchayat office (Rank I) which is followed by blocks level various office (Rank II), which was again followed by subtown office (Rank III). This table showed that farmer of Darjeeling hills mostly rely on panchayat and block level office, and if they received basic information regarding various economical utilization of available resource in sustainable manner, will be beneficial not only to them but also future generation too. Further, the use of the media for updating their knowledge and skill regarding resource management revealed that the farmers most often used farm/agriculture publication (Rank I) for getting information on agriculture and other available natural resource information etc. followed by Television (Rank II) and newspaper (Rank III), respectively (Table 4). All of these factors affect the farmer knowledge level and which ultimately affect the economy of farming system.

Table 1: Utilization of available natural resource by farmer under terraced cultivation (N=120) .

Sl.no.	Farming enterprises	No. of cultivators involved in farming enterprises (N =120)	Percentage (%)
1	Crop	25	20.83
2	Crop under agroforestry	29	24.16
3	Crop + Poultry	21	17.5
4	Crop under agroforestry + Poultry	20	16.66
5	Crop under agroforestry + Poultry +Milch cattle	16	13.33
6	Crop + Poultry + Milch cattle	11	9.16

Table 2: Educational qualification of the selected farmers who practice natural resource utilization in their farming system.

Sl.no.	Education	No.	Percentage	Ranking
1.	Illiterate (0)	23	19.16	III
2.	Primary (1)	16	13.33	V
3.	Middle School (2)	26	21.66	I
4.	Madhyamik (3)	25	20.83	II
5.	Higher secondary (4)	17	14.16	IV
6.	Graduate (5)	13	10.83	VI
7.	Above graduate (6)	1	1.6	VI

Table 3: Cosmopolitenes of farmers (N=120) involved towards natural resource management.

Sl.no	Place	Most often (3)	Often (2)	Sometime (1)	Never (0)	Total score	Ranking
1.	City	-	9	23	88	41	VII
2.	Dist. Town	13	18	32	57	107	IV
3.	Sub. Town	26	34	53	7	121	III
4.	Panchayat	29	53	38	-	231	I
5.	SAO/ADO office	20	32	36	32	100	V
6.	B.D.O office	19	35	28	38	155	II
7.	RRS	7	37	33	43	91	VI

Table 4: Media exposure of the farmers (N=120) towards natural resource conservation.

Sl.no	Mass media	Most often (3)	Often (2)	Sometime (1)	Never (0)	Total score	Ranking
1.	Radio	15	37	29	39	148	IV
2.	Newspaper	26	33	11	50	155	III
3.	Farm/Agril. publication	28	43	23	26	193	I
4.	Film show	13	29	38	40	135	V
5.	Television	30	22	36	32	170	II

Critical issue which were need to utmost care for conservation of available natural resource has been pointed out as follows :

3.1.1. Soil degradation: Soil degradation has raised some serious debate not only in Darjeeling but also whole Darjeeling-Sikkim Himalaya range. It refers to the decline in soil's inherent capacity to produce economic goods and perform ecologic functions. It is the net result of dynamic soil degradative and restorative processes regulated by natural and anthropogenic factors. The degree of soil degradation depends on soil's susceptibility to degradative processes, land use, the duration of degradative land use, and the management. Soil and water degradation are also related to overall environmental quality, of which water pollution and the "greenhouse effect" are two major concerns of global significance. Soil quality is the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promotes plant and animal health and thus has a profound effect on the health and productivity of a given ecosystem and the environment related to it. Darjeeling- Sikkim Himalaya is characterised by diverse agroclimatic and geographical situations. The low area under agricultural crops is due to natural corollary of the physiographic features of the region, as major chunk of the land has more than 15 per cent slope, undulating topography, highly eroded and degraded soils, and inaccessible terrain. Continuous dilution of the forest cover in the region due to exploitation of forest resources, firewood, and timber collection is posing the most crucial problem resulting in poor soil health and environmental degradation. The most serious effect of soil erosion results loss of most fertile top soil and exposure of infertile acid subsoil, decrease of plant available water capacity, degradation of soil structure, non uniform removal of soil surface and ultimately decrease of economic return on production (Sharma *et al.*, 2001). Most of the soil of Darjeeling hill has pH less than 5.2, where growth of the plant roots is restricted resulting low productivity due to aluminum toxicity. The field experiments conducted on acid soils gave the maximum yield of maize, wheat and soybean, when limestone rates were 1-2.5 equivalent of exchangeable aluminum and soil pH raised around 5.5 (Patiram *et al.*, 1991). However, the limestone rates based on exchangeable aluminium cannot become popular in the hilly terrain of Darjeeling, because here inputs are carried on the head to the distant fields. Organic matter in one form (cattle manure) or other is used in Darjeeling to replenish the soil fertility for sustainable land management in maintaining soil quality through its effect on soil structure, water-holding capacity and nutrient supply. The addition of organic matter to acid soil reduces the soluble and exchangeable aluminum temporarily by forming complexes with organic matter to provide favourable environments for plant growth in addition to improve the physical, chemical and biological properties of soil (Patiram, 1996). Multiple cropping, inter-cropping, relay cropping, inclusion of legumes in rotation, strip cropping etc. ensure better crop productivity, besides maintaining soil fertility.

3.1.2. *Deforestation and related issues*

Degradation of natural forests was a major problem. Mankind has been destroying forest for millennia ever since agriculture was discovered (William, 1989). In the Darjeeling Himalaya too, deforestation is argued to be not a recent phenomenon. It has a long history, being well established in late eighteenth century at least (Mahat *et al.*, 1986). In Himalaya, degradation of forest cover is a primary problem which gives way to a variety of problems. With deforestation of slopes many environmental degradation processes like soil erosion, slope failures, depletion of soil fertility, scarcity of fuelwood and fodder, increased overland flows, reduced ground water recharge, loss of biological diversity are accelerated. Siltation of river beds in lowlands is the repercussions of vegetal cover degradation in the hills. However, extent of impairment of various processes attributed to vegetal degradation depends upon a range of other factors including past histories, intensity of removal of natural vegetation, patterns of natural regeneration and /or other human interferences (Alford, 1992). For understanding the role of forests in the life of the Darjeeling Himalayan mountain societies, it is important to understand the inter-linkages between agriculture, animal husbandry and forests. Over the centuries forests have been converted to agriculture fields, grazed by increasing animal populations. This close relationship between population growth, expanding area under subsistence crops, and increase in livestock numbers is closely related to intensifying demands on the forests. While there are serious problems in determining total available forest cover, biomass productivity, biomass demands and actual consumption, there are also conflicting estimates of the amount of forest/support land needed to support one unit of cultivated land. These somehow deplete the natural resources of the specified study area.

3.1.3. *Forest fires*

Occasionally, forests are intentionally set to fire to kill trees to obtain fuel wood and construction materials, and also to extend the area of the adjoining agricultural lands. Forest fires, especially those in the high-altitude pine (*Pinus wallichiana* A.B. Jacks.) forests are set to enhance the growth and yield of the high-priced morel mushrooms (*Morchella conica* L., *M. esculenta* L., etc.). The pastures are regularly subjected to fire to produce tender grasses. Consequently, many valuable herbs flourishing in those habitats are heavily affected. The fire also destroys the alpine butterfly belonging to the genus *Leptopteris* whose larvae are the host for the highly reputed and endangered medicinal fungus *Cordyceps sinensis* (Berk.) Sacc., ultimately threatening the existence of even the fungus. Mostly the fires are beyond control, and result in severe losses destroying the herbs, roots and rhizomes at ground level and even the clumps. Lower branches of tall trees are also seriously affected by the fire. Organic matter in the upper layer of the soil is usually destroyed resulting in the disappearance of many valuable biological species from the area. The burning process practice throughout the hills, had tremendous effect on soil ecosystem. Burning of above-ground vegetation showed an increase in pH and cations and a decrease in carbon and nitrogen contents in the surface soil. Quick release of nutrients especially cations after burning has been observed in recent past. The organic carbon content of soil decreased drastically after burning because of oxidation loss. Rise in pH, temperature, and bases of the soil might have increased the microbial activity after burning which in turn resulted in accelerating mineralization of organic N to inorganic forms.

3.1.4. *Overgrazing*

The shortage of fodder and other feeding materials has resulted in overgrazing in the pastures and overlopping of fodder trees in the forests (Mukherjee, 2013 c). About three-quarters of the fodder come from the forest and grassland, thus posing pressing threat to the Darjeeling biodiversity and adversely deplete the natural resources.

3.1.5. *Overexploitation*

A major proportion of the non-wood forest products, especially the medicinal and aromatic herbs collected from the wild, is meant for export. Hence, the quantities of different forest products collected are mostly determined by the demand from abroad. At the same time, the local collectors, mostly belonging to the poorer classes of the community, are being attracted by the market prices for some items that have gone through the roof. As a consequence, raw materials are overharvested by the removal, for example, of immature plants, roots, tubers and rhizomes, or by over pruning. As an outside interest dictates the price and quantity of raw materials extracted, a major part of local ecosystem has suffered irreversible harm.

3.1.5. *Foul play with the climate*

The Darjeeling - Sikkim Himalayan agriculture systems exhibit an ecosystem diversity which is dependent on micro-climatic and biophysical factors in exceptionally fragile and varying topography. Climate change events observed and recorded here have given rise to mudslides in terrace risers (in khet and bari systems) and productivity decline of crops (e.g., cardamom, ginger, orange, paddy, maize, wheat and buckwheat etc.) resulting in emerging food insecurity in the mountain region (mainly to those farmers living in highly inaccessible areas). Farmers remarked that the sowing of maize in the sub-tropical zone has shifted by 20-25 days, while sowing at temperate zones remains the same. Similarly, the harvest of maize remains the same in the sub-tropical zone while harvest time has shortened by 15-20 days in the temperate zone. Information on temperature rise and untimely rainfall and its impact on agriculture have been reported

by the farmers by their day to day observation. Ecosystem services trade-off is a matter of concern due to land use change.

3.2. Sustainable management of resources through improved technology

As per our study and work for last nine year revealed that, Darjeeling ecosystem is going to be fragile day by day due to enormous exploitation of available natural resource (Mukherjee, 2012). These can be checked through some improved management practices, I just point out that strategy which is intense need of an hour.

3.2.1. Conservation tillage

Conservation tillage is one of the most important measures to protect agro-ecosystem as a whole. In this system, managing crop residue on the soil surface with minimum disturbance (Ghosh *et al.*, 2010). The stubble mulch or reduced tillage/minimum tillage, no tillage and direct drill are few components which become quite effective measure throughout the Darjeeling – Sikkim belt. The objectives of this practice are (i) to leave enough plant residues on the soil surface at all times for water, and wind erosion control, (ii) to conserve soil and water and (iii) to reduce energy use. Study at RRS, Kalimpong revealed that with treatment with conservation tillage, enhance soil temperature and this will be very effective for nutrient mobilization and microbial activity in hilly region (Table 1).

Conservation tillage procedures must be related to the particular site. Their successful application and use over a wide range of soil conditions depends on matching the procedure to soil type, crop cultivar, climatic factors and other aspects of the environment (Mukherjee, 2008).

Table 5 : Effect of tillage on maximum soil temperature at 5 cm depth under different crops two weeks after planting in Kalimpong, Darjeeling(14th May, 2012).

Treatment	Maximum soil temperature (°C)			
	Maize	Blackgram	Soy-beans	Cow-peas
Ploughed (Tillage)	29.9	30.3	31.4	30.8
No-tillage	21.6	22.4	21.4	20.4
Difference	8.3	7.9	10.0	10.4

The priorities for the development of conservation tillage systems include:

- ❖ the development of cheap alternative methods of weed control, especially in hill for farmers with few resources;
- ❖ the development of effective and specific herbicides to control weeds, where the farmers can afford them (such herbicides should not harm subsequent crops);
- ❖ the development of suitable crop rotations including cover crops, and improved cropping sequences that result in more effective storage of rainfall and efficient utilization of soil available water,
- ❖ provision of appropriate equipment for planting and fertilizer application, and
- ❖ the breeding of crop cultivars that are adaptable to conservation tillage systems and also have characteristics that aid in erosion control as well as improve soil fertility.

Table 6 : Factors affecting the choice of tillage practice under terraced cultivation are mainly pointed out as:

Soil factors	Climatic factors	Crop factors	Socio-economic factors
Relief (slope). Erodibility Erosivity Rooting depth Texture and structure Organic-matter content Mineralogy	Rainfall amount and distribution. Water balance Length of growing season Temperature (ambient and soil) Length of rainless period	Growing duration Rooting characteristics Water requirements Seed	Farm size Availability of a power source Family structure and composition Labour situation Access to cash and credit facilities

3.2.2. Resource conservation

Resource conserving and environmental friendly production strategies are desirable for agrarian economies. Grass cover is the key factor in improving soil physicochemical health by assuring regular addition of organic matter,

thus reducing surface runoff and soil erosion. Some promising perennial grasses like *Setaria*, Citronella, Guinea, Napier, and Broom grass were tested and found to be very effective in Darjeeling Himalaya and also influence on soil physicochemical properties. Some of the successful resource conservation practices are briefly described in the following section.

3.2.2.1. Mulch farming

Mulch farming is a system of maintaining a protective cover of vegetative residues such as straw, maize stalks, fern fronds and stubbles (wheat and rice) on the soil surface at all times. The system is particularly valuable where a satisfactory plant cover cannot be established at the time of year when erosion risk is greatest. The beneficial effects of mulching include protection of the soil surface against raindrop impact, decrease in flow velocity by imparting roughness, and improved infiltration capacity (Mukherjee, 2010). It also enhances burrowing activity of some species of earthworms (e.g. *Hyperiodrilus* and *Eudrilus* spp.) which improves transmission of water through the soil profile and reduces surface crusting and runoff and improves soil moisture storage in the root zone.



Fig. 2: Mulch farming practice for cultivation of Ginger.

3.2.2.2. Soil conditioners

The size and stability of the pore spaces and the infiltration rate have been found to be improved by application of soil conditioners. Soil conditioners are oil or rubber based emulsions of poly-functional polymers that are capable of developing chemical bonds with the clay minerals in the soil, resulting in the formation of aggregates. Effective temporary erosion control achieved when the whole soil surface is covered has been found to be comparable with the 70% coverage required for erosion control using mulches and plant covers

3.2.2.3. Cover crops

Planted cover crops such as Cowpea, *Setaria* spp., broom grass, *Stylosanthes* spp. and *Glycine* spp. provide another technique of achieving *in situ* mulch. Following with suitable cover crops conserves soil water improves water use efficiency, weed control and soil organic matter. It is the most satisfactory method of building up the organic content of soil. The effectiveness of cover crops in soil and water conservation however depends on species characteristics including ease of establishment, vigour of growth, depth of rooting, rapidity of establishment of surface cover etc.

3.2.2.4. No-tillage farming

Sound soil management is essential to the success of soil conservation schemes because it ensures good plant cover. No-tillage involves a method of seeding through a crop residue mulch by opening a narrow slot in the soil for seed placement without mechanical or secondary tillage operations. Chemical weed control is used. The beneficial effects of no-tillage in soil and water conservation are widely recognised in Darjeeling climates where the system seems to have a broad application. The benefits include soil moisture conservation due to reduction in storm runoff, improved infiltration capacity, enhanced earthworm activity, and reduced evaporation loss. It also reduces soil erosion and maintains organic matter content at high levels. The effectiveness of no-tillage farming in soil and water conservation is improved when used in association with planted cover crops.

3.2.2.5. Ploughing

Plough operations help to keep the upper soil layers porous at least for a short time especially in compact soils that restrict root development and infiltration. Ploughing can help to minimise runoff by assisting infiltration. To be effective over a longer term, the soil aggregates must be stable and resistant to breakdown under raindrop impact. A wide range of special tillage operations involving soil inversion, chiselling, subsoiling or deep tillage (for soils with an impending layer within rooting depth) have been found to be beneficial in improving surface detention, storage, infiltration, root development and by minimising soil hardening. The effectiveness of plough in soil and water conservation also depends on the conditions under which it is carried out and its frequency. Recent studies have emphasised the importance of cultivating only when soil conditions, particularly the soil moisture content are right to avoid structural breakdown and smearing.

3.2.2.6. Alley cropping

Alley cropping is an agro-forestry system integrating trees and shrubs with annual food crop production and very often found under Darjeeling – Sikkim Himalaya. In this system arable crops are grown in the spaces between rows

of planted woody shrubs or trees, which are pruned during the cropping season to provide *in situ* green manure and to prevent shading of crops. The beneficial effects of the system in reducing erosion, surface runoff and soil moisture loss depend on the proper choice of the protective species. Runoff and erosion is reduced by the physical barrier of the hedgerows, and also by the better physical condition of the soil under the hedgerows, resulting from higher faunal (earthworm) activity, which increases water infiltration. Promising results have been obtained in alley-cropping arable crops (such as maize) with *Gliricidia* and *Leucaena* and Tea cultivation with the shade plant *Populusn deltoides* and other shading plant. Leguminous species such as *Leucaena*, *Alnus nepalensis* and *Gliricidia* grown in hedgerows in alley farming can yield large quantities of biomass and nutrient yield under terraced cultivated land of this part of eastern himalaya.

3.2.3. Management of natural resources

Soil and water conservation are interrelated methods that control and conserve water on hillsides also conserve the soil and control erosion. Physical conservation measures involve land shaping, the construction of contour bunds, terraces and ridges. Broadly, farmers have indicated three ways to protect resources by means of mechanical, agricultural and vegetative.

3.2.3.1. Mechanical measures

In Darjeeling hill farmers usually construct terraces for cultivation of crops, vegetables and maintaining livestock. They construct terrace in such a form, that help for manage rainwater in some pocket of Darjeeling hills particularly in Kalimpong Block II of lava region. Construction of terraces depends upon space and grades of land. According to scientific recommendations cultivation is allowed to 33 per cent of land slope. But in the Darjeeling – Sikkim hills, farmers usually make terraces from top to bottom of the mountain terrain without taking into account the land slope. With terraces they construct loose boulder retention walls (risers) by putting grass over them. These grasses keep both stones and the land intact. Cement and sand are scarce materials in the hills. In making risers farmers simply arrange boulders of the proper size along the terrace wall. It retains the soil perfectly and gradually gets stabilised. Farmers make the slopes of the terraces inwards to check soil erosion and enhance *in situ* moisture conservation. Soils are gravelly and have a high rate of percolation. Due to rainwater retention enough moisture becomes available to the crops. On mild slopes farmers construct shoulder bunds to protect their lands from soil erosion and grow vegetation over the bunds, particularly grasses for binding the soil. Farmers make brushwood or longwood check dams across the drainage channels for controlling soil loss by means of local materials and they are economical.

3.2.3.1.1. Practices that reduce runoff by controlling water movement over the surface

The principle of these practices is to minimise the concentrations of runoff volume and to slow down the runoff velocity, allowing the water more time to soak into the soil, limiting its capacity to transport soil particles and diminishing its ability to cause scour erosion.

3.2.3.1.1.1. Strip cropping

This is farming of sloping land in alternate contoured strips of intertilled row crops and close-growing crops (for example, a cover crop or grass) aligned at right angles to the direction of natural flow of runoff. The close-growing strip slows down runoff and filters out soil washed from the land in the intertilled crop. Usually, the close-growing and intertilled crops are planted in rotation. Strip cropping provides effective erosion control against runoff on well-drained erodible soils on 6 to 15% slopes. The width of the strips is varied with the erodibility of the soil, and slope steepness.

3.2.3.1.1.2. Contour farming

Contour farming involves aligning plant rows and tillage lines at right angles to normal flow of runoff. It creates detention storage in the soil surface horizon and slows down the runoff thus giving the water time to infiltrate into the soil. The effectiveness of contour farming in water and soil conservation depends not only on the design of the system but also on soil, climate, slope aspect and land use. the beneficial effect is least marked on compact or slowly permeable soils because these become saturated quickly compared to highly permeable soil. Contour bunds are another important physical measure. These are earth banks, 1.5 to 2 m wide, forming buffer strips at 10 to 20 m intervals across the slope.



Fig. 3. Contour trenches



Fig. 4. Bench terracing

3.2.3.1.1.3. Terrace farming

Terrace farming involves earthworks made at right angles to the steepest slope consisting of an excavated channel on the uphill side, the spoil from which forms a bank on the downhill side. It converts a steep slope into a series of steps with horizontal or nearly horizontal ledges and vertical walls of stone, brick or timber between ledges. Terraces are built by various techniques and called (according to method of construction) bench terraces; diversion terraces, broad-based and narrow-based types, channel terraces, retention terraces etc.

3.2.3.1.2. Efficient water management technique effective in Darjeeling - Sikkim hill

These include mainly the indigenous methodology practice since long back. Mainly these are as

3.2.3.1.2.1. Multipurpose water management system

Here integrates land, water and farming systems by protecting soil erosion, conserving water for irrigation and domestic purpose. This is practice under mid to high altitude range (1400 – 1600 m asl) where combination of flat and raised bed are available (Mukherjee, 2013 a). In this system, every stream rising from the hill is trapped soon after it emerges from forest, channelized at the rim of valley and diverted by network of primary, secondary and tertiary channels to a water harvesting zone.

EFFECTIVE WATER CONSERVATION MEASURES IN HIGH HILL



Fig.5 : Water harvesting through interrelated channel pipe rain water (Alagariah, 1600 m asl)



Fig.6 : Bamboo drip irrigation technique



Fig.7: Roof top water harvesting at Lava (2000 m asl)

3.2.3.1.2.2. Bamboo drip irrigation system

This is a very common practice in throughout Darjeeling hill. Water application on hill slopes for irrigation of plantation crops poses serious problems of soil erosion. The tribal farmers have developed the indigenous technique of Bamboo drip irrigation (Mukherjee, 2010). In doors area where, betel vines planted with arcanut as the supporting tree are irrigated with this system, in which water trickles or drips drop by drop at the base of crop. In this system water from the natural streams located at higher elevation is conveyed with the use of bamboo channels, supported on ground surface by wooden or bamboo supports, to the site of plantation through gravity flow. Discharge of water upto 25 liters/min can be easily managed by manipulating the distribution systems. Water distribution is done with the use of bamboo channels, bamboo supports; water diversion pipes and strips. The whole system enables in distribution of 15 to 25 liters of water without any leakage at point. There may be several diversions at each stage depending on the availability of water resources and number of the plants to be irrigated. The system is laid out in such a way that ground clearance of channels reduces from few meters to 10 cm to 15 cm and this is done by reducing the height of channel supports.

3.2.3.1.2.3. Roof top water harvesting

In Darjeeling-Sikkim Himalaya range most of the hills are steep having slope more than 50 per cent and are separated by deep river gorges. Despite of heavy monsoon rain, the people face acute water problems every year in the dry season. The geological formation does not permit water retention; runoff is quick and springs and small streams dry up when there is no rain. Roof top harvesting structures for drinking purpose have been developed locally and now spread in the entire Darjeeling hill (Mukherjee, 2013 b). The impact of recharge through these structures to ground water regime is local, but if implemented on a massive scale, it can raise the water level remarkably and increase the sustainability of water supply through shallow depth ground water structures. It has proved to be quite successful. Most houses are built with sloping roofs with galvanized iron sheets to be quite successful. Most houses are built with sloping roofs with galvanized iron sheets which are conducive to rain water harvesting. A common method of storing rain water is to place horizontal rain gutters along the sides of sloping roof, which is normally made of corrugated iron sheets. Rain water pours into a pipe connected to the tank which is mostly made from GCI sheets or galvanized plain sheets. But many people have started using reinforced cement concrete tanks, located in the court yard or under the house.

3.2.3.1.3. Vegetative measures for natural resource management

Hill farmers grow trees of economic value and suited to their requirements. Cultivation of pterodophyte plant (such as fern) under sloppy land help to conserve soil and water erosion problem (Fig. 11). In order to conserve soil and water grow grasses for ground cover such as *Eulaliopsis binnata*, *Chrysopogon fulvus* and agave sps. Shrubs like *Ipomea icarnea*, *Arando donex*, *Dendrocalamus strictus*, napier grass, *Vitex negundu*, *Morus alba* and *bagrera* are grown, and in wild form are available *bhang*, *lantana*, *sweet neem*, etc. Among trees they grow *Grewia pitiva*, *Bauhinia* sps., *Albezia labek*, *Timla*, *Gainthietic*, to meet fuel and fodder requirements. For the development of horticulture in the Darjeeling the trees grown are citrus, pear, peach and plum. Further lot of scope of grow high value medicinal plants particularly *Swertia chiratyita*, *Valeriana jatamansi*, *Podophyllum hexandrium* etc. The uncontrolled commercial extraction has significantly eroded the Darjeeling hill medicinal plant resources, and particular species have gradually become more difficult to find in a given locality where they once flourished (Mukherjee, 2009). Thus the availability of the high-altitude herbs supplying underground parts, e.g. *Aconitum ferox* Wall., *A. heterophyllum* Wall. ex Royle, *A. spicatum* Stapf., *Dactylorhiza hatagirea* (D.Don) Soo, *Daiswa polyphylla* (Sm.) Rafu. var. *wallichii* Hara, *Fritillaria cirrhosa* D.Don, *Nardostachys grandiflora* DC., *Panax pseudoginseng* Wall., *Picrorhiza scrophulariiflora* Pennell, *Podophyllum hexandrium* Royle, *Rheum australe* D.Don, which were once abundant, has declined drastically in recent years. The supplies of middle- and low-altitude herbs like *Asparagus racemosus* Willd., *Dioscorea deltoidea* Wall. ex Griseb., *Rubia manjith* Roxb. *Valeriana jatamansi* Jones, and many epiphytic orchids, notably *Dendrobium densiflorum* Lindl., *D. longicornu* Lindl., and *D. macraei* Lindl., have reduced considerably (Mukherjee, 2008).

CONSERVATION OF HIGH ALTITUDE MEDICINAL PLANT (under natural resource management programme)



Fig. 8 : Conservation of endangered medicinal plant at an altitude of 2000 m asl (lava) under RRS, UBKV.



Fig. 9 : Conservation of Valeriana jatamansi RRS, UBKV, Kalimpong



Fig. 10: Conservation of Swertia chirayita (Sherpa Gao, Lava)



Fig. 11: Soil and water conservation through fern

Some of observed traditional farming practice become useful for natural resource management are pointed out as :

- Darjeeling hill farmers, use a special type of traditional plough, which effectively plough the soil without much disturbance of soil ecosystem. Other types of ‘improved’ ploughs do not work in the hills as the soil is gravelly and not deep.
- Under rainfed conditions farmers in hill regions plough their land several times before the onset of rain to conserve water and increase water retention capacity.
- Farmers plough their land straight instead of in circles and open parallel furrows for rainwater harvesting and retaining moisture. However, there is a recommendation to plough the land across the slope to check erosion.
- Here farmers prefer mixed cropping for minimising risks under rainfed conditions and creating ground cover for checking runoff and soil loss. They grow legumes with maize and ginger or turmeric with maize.
- After sowing ginger, colocasia and turmeric, farmers use paddy straw, wheat straw or leaf litters as mulch to ensure proper germination.
- Farmers do not practise weeding and interculturing in the maize crop because of soil conditions and the requirement of fodder in the rainy season.
- Farmers of the high hills zone usually conserve water by only digging the land.
- In the hills grower grow mainly *Koddo*, *mandua*, *jhingora* and *guar* since time long and they effectively help to conserve the soil to wash away. Because of recent developments they have been attracted towards off-season vegetables, e.g., peas, tomatoes, etc.

The upland farmers have developed protective belts along the edges of the terraces of their farmland using a number of multipurpose agro-forestry species such as *Schima wallichii*, *Engelhardtia spicata*, *Bridelia retusa*, *Bischofia javanica*, *Bombax ceiba*, *Rhus semialata*, *Castanopsis tribuloides*, *C. hystrix*, *C. indica*, *Ficus sp.*, *Duabanga grandiflora*, *Erythrina arborescens*, *Gynocardia odorata*, *Juglans regia*, *Jambosa formosa*, *Litsea polyantha*, *Morus indica*, *Quercus sp.*, *Terminalia chebula*, *Symplocos theifolia*, *Saurauia punduana*, *Toona ciliata*, *Betula cylindrostachys*, *Acer oblongum*, *Beilschmiedia roxburghiana*, *Cinnamomum impressinervium*, *Engelhardtia acerifolia*, *Ehretia wallichiana* etc. In the last ten years farmers have introduced nitrogenfixing species (*Flemmingia sp.*, *Indigofera sp.*, *Erythrina sp.*, *Gliricidia sp.*, *Desmodium sp.*, *Albizia sp.*, *Alnus sp.*) and stabilised the steep farmlands by designing contour hedge-rows (Umashankar, 2005). Recently farmers have introduced permanent crops such as banana, mandarin orange, plums, pears, guava, fodder species such as broom grass and trees with a variety of pulses and cereals as under-storey crops. For soil fertility maintenance, farmers have introduced bio-composting, vermi-composting, production of farmyard manure, mulching and use of green manure (Sharma *et al.* 2000). In the rain-shadow areas of Darjeeling, rain and roof water harvesting has been initiated (Fig.7). Bench terracing was a traditional practice often used by farmers practicing agriculture in the steep slopes. This has been revived recently to prevent runoff, soil stabilization from degradation, fertility maintenance and moisture retention. Development of farm-based agro-forestry has a possibility to be an adaptive system for mitigating climate change impacts. Due to shortage of farm-labour, the farmers have developed farm-based agro-forestry for growing fodder and fuel-wood. The cultivation of vetiver, *Thysanolaena agrostis* and other multipurpose fodder species and medicinal plants under the *Alnus nepalensis* trees replacing large cardamom has been recently observed widely in several villages of Darjeeling. The practice of using nitrogen fixing *Alnus* as shade trees has been adopted by the indigenous communities to maintain the soil fertility and increasing the productivity (Sharma *et al.* 2004, Binkley *et al.* 1992). This has supplemented the farmers with additional incomes while bringing back the ecological resilience of the system.



Fig. 12: Cultivation of large cardamom with *Alnus nepalensis* help to improve soil fertility (Phalut, Darjeeling(7000 m asl))



Fig. 13: Broom grass cultivation under terraced land of Darjeeling hill
(Lava, Maypate village)

4. CONCLUSIONS

Over-exploitation of natural resources by growing population resulted in various severe problems. Destruction of vegetation has resulted in land degradation, denudation, soil erosion, landslides, floods, drought and unbalanced ecosystems. Critical issue which were need to utmost care are soil degradation, landslide, deforestation and overexploitation of natural resources. Few of the improved technique like conservation tillage and improved resource management become effective to somehow the above said problem. Major goals of this analytical paper is to suitable way management of available resource in the better way keeping in mind the farmer economic return too.

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