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Sustainability of temperate/ alpine pastures vs landform and soil status: A case study of Sikkim using GIS and RS techniques

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Abstract

Temperate/ alpine pasture lands and associated landforms and soil status of Sikkim were assessed using IRS-P6 (LISS-III) data. Intensive field survey of 14 sites located at different elevations in mid hills and high hill zones was done for soil status, forage production and landform features. The area under alpine pastures in high hill zone was 7.38 % of total geographical area whereas it was 6.76% in mid hills. The various soil characteristics of alpine pastures land in Sikkim were: pH (4.14 to 6.34), organic matter (0.95-2.82%), available N (319.6-1402.7 kg/ha), available P (10.39-29.06 kg/ha), and K (103.65-599.6 kg/ha). These soil characteristics in alpine pasture lands in varying altitudes influence the forage production (0.31 – 3.25 t DM/ha) and CP content (8.5 – 19.5 %). About 36.5% of the total pasture lands (14.13% of the total area) were at various stages of degradation. Pasture lands (43.65%) located at different altitudes and slopes in mid hill zones were found to be more susceptible to soil erosion/ depletion and landslides. The study reveals that the sustainability of pasture lands and pasture production depends upon the soil health and associated landforms.

Key words: Elevation, GIS, GPS, Pastures, Remote sensing, Soil, Sustainability, Sikkim

Introduction

Geomorphological features exert an indirect, yet, powerful influence on natural pastures. Their effect on soil condition, surface water, slopes and gradients are major factors influencing the habitat of plants (Pathak *et al.*, 2005). Landform is a three dimensional feature on the earth's surface formed by the natural processes. It is defined as the study of characteristics, origin and development of landforms which are specific geomorphic features on the earth's surface, ranging from large-scale features such as plains and mountain ranges to minor features such as individual hills and valleys (Blaszczynski, 1997).

The shapes of terrain, *i.e.*, landforms, influence the flow of surface water, transportation of sediments or pollutants and determines climate on local and regional scales. Further, natural phenomena and habitats of plants are directly related to landform patterns and the relative position with a landform (Blaszczynski 1997; Blaschke and Strobl, 2003). The sustainability of natural temperate/alpine pasture lands are dynamically dependent on the nature and type of landform and surface soil (upto 15 cm depth) on one hand and nature, type and pattern of utilization on another hand. Surface materials, slope, denudational process and grazing pressure as well as human induced factors directly affect the sustainability, productivity and aerial extent of natural temperate/alpine pasture lands. Multi-spectral satellite imagery provides accurate information about the landcover, *i.e.*, pasture lands. The remotely sensed satellite data supported with GPS (Global Positioning System) linked ground information provides base line information on extent, condition and production *etc.* of pasture lands. These spatial and attribute information can be easily integrated using GIS (Geographical Information System) for the generation of geo-referenced layers on different aspects of landform, soils and natural pastures on local, regional or state level depending upon the resolution of satellite data and ground truthing (GT) techniques.

The state of Sikkim spreads over an area of 7,096 sq km. and is situated on the flanks of eastern Himalayas (27°00'46" N to 28°07'48"N and 88°00'58"E to 89° 55'20'E). Sikkim (Fig.1) is administratively divided into four districts *viz:* north Sikkim (4226 km^2), west Sikkim (1166 km^2), east Sikkim (954 km^2) and south Sikkim (750 km^2). Due to the terrain, the state of Sikkim experiences natural and

hazards like soil erosion, land sliding and land degradation, which affect pasture sustainability and production. Sikkim has a varied topography defined with high elevated mountains and deep valleys. Its altitude varied from 244m at Melli to 8,598m at Mt. Kanchandzonga forming the mountaineering climate. The climate of Sikkim is characterized by mild summer and cool winter, which affects natural grasslands, soils and forest cover. About 11.5% area of Sikkim is permanently under snow cover. The fringe area of glacial and snow covered area on mid slopes and high uplands are also covered for a period of 4-6 months. These areas are best suited lands for alpine pastures. In this paper efforts have been made to understand the impact of soil fertility status, topography and other physical characteristics of land on the sustainability of temperate / alpine pasture lands.

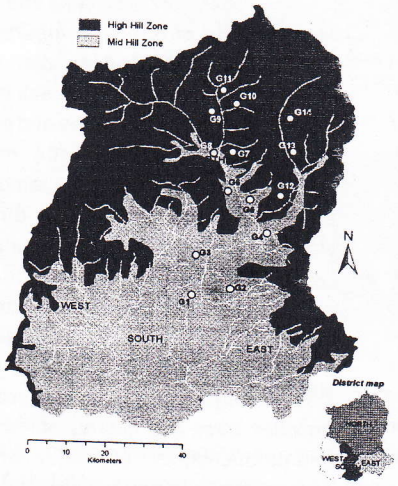

Fig.1: Location of sample sites in different hill zones

Materials and Methods

Study Area: The base map of study area, *i.e.*, Sikkim was generated using SOI map on 1:250,000 m scale. ArcGIS - ArcInfo workstation was used for the generation of different thematic layers *viz.*, administrative boundary, drainage, forest boundary and topographic feature and geo-spatial analysis *etc.* Multi-spectral landset data of 1998 and IRS-P6 (LISS-III) data of year 2009 (Fig. 2) were selected, corrected, geo-referenced and classified using ERDAS Imagine professional software.

Fig.2: Satellite Image of Sikkim

Selection of sample sites and GPS data recording: Sites were selected from different altitudes (1045m to 4065m) and from different pasture lands (Fig. 1) for the identification and characterization of soil, landform and existing pasture production. The entire state was grouped into two groups namely high hill zone (2500-4500m amsl) and mid hill zone (up to 2500m amsl). In this investigation total 14 sites (seven each from both zones) were selected (Fig.1). During the selection of sites accessibility and proper representation of pasture lands were also considered. The size of each site was 32m x 32m. From each site, five samples were collected and the analyzed data was pooled. During the selection of sites, emphasis was also given on topography of the pasture lands. The GPS location, altitude and aspects of each site were recorded (Table1) using Garmin GPS Map276.

Ground data recording and analysis: Soil samples were collected from five points in each site (32m x 32m). Samples were taken from approximately 15 cm below the top surface with suitable sampling tools. After recording the fresh weight, samples were sent to laboratory in sealed packets for the detailed analysis of pH, electrical conductivity (EC), bulk density (BD), available nitrogen (N), organic carbon (OC), available Phosphorus (P) and available potassium (K). Analysis of the soil samples for different nutrients was done using standard laboratory procedures. Fresh weight of plant samples (forage biomass) was recorded on per m^2 basis. Pasture lands located in both zones were grouped in to different landform unit on the basis of topography, relief, physiography and aspect to understand the dynamic relationship between pasture productivity and its spatial location.

Table1. Selected sites in Sikkim

Category	GPS Point	Altitude (m)	Latitude (DD)	Longitude (DD)
Mid Hill	G1	1045	27.46000	88.52774
	G2	1490	27.41056	88.53868
	G3	1569	27.43649	88.61660
	G4	1645	27.57614	88.65411
	G5	1968	27.65673	88.60770
	G6	2006	27.73231	88.54474
	G7	2499	27.66943	88.73393
High Hill	G8	2884	27.75954	88.54395
	G9	4065	27.91553	88.53015
	G10	4062	27.90586	88.52705
	G11	3285	27.73868	88.74003
	G12	3516	27.83342	88.55256
	G13	3935	27.89897	88.53773
	G14	3644	27.80121	88.70637

Result and Discussion

Landform

The hills of Sikkim mainly consist of gneissose and half-schistose rocks, making their soil brown clay and generally poor and shallow. Distinct micro-morphological features of Sikkim include terraces and floodplains, valley side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle shaped depressions, terrace isles, sickle shaped rags, beveled plains, undulating plains with deeply dissected valleys, glacial or peri-glacial deposits, related sedimentary structures crevasses, soil series or poly pedan and gorges. Mukhopadhyay (1998) has also reported that the trunk stream Teesta and its innumerable tributaries were important agents of denudation and deposition which moulds the landscape of Sikkim.

Major portion of the Sikkim territory including Gangtok is covered by the pre-cambrian rock and is much younger in age than the hills. The rock consists of phyllites and schist and therefore the slopes are highly susceptible to weathering and prone to erosion. Pasture lands situated on these slopes were found in highly degraded condition due to heavy loss of top soils. This combined with the intense rain, causes extensive soil erosion and heavy loss of soil nutrients through leaching. As a result, at many places temperate/ alpine pastures were found at various stages of degradation where either topography was very rugged or the grazing pressure was very high. It was evident from the field survey, especially in high hills near Yumthang, where heavy infestation of unpalatable shrub species were found at degraded pasture lands.

Hill tops (Xe-distance) and steep slopes were badly affected with denudational processes and only bare rocks were visible in Lachung valley.

High hill zone (52.97% of the total area) covers northern and north-eastern part of the state while mid hill zone (47.02%) covers south and south-eastern parts including the foot hills (Table 3). Highly undulating uplands of the northern Sikkim are separated with many narrow valleys. Anticlines and upper reaches are covered with snow and glaciers (11.5% of the total geographical area). During the short span (3-4 months) of summer, between June/July – September/October, highly nutritious pasture grasses (crude protein ranges between 11.4 – 23.0%) on these hills are used by grazing animals (mainly yaks). Pasture lands located in both zones were grouped in to different landform unit on the basis of topography, relief, physiography and aspect to understand the dynamic relation between pasture land productivity and its spatial location. The study reveals that alpine pasture lands were associated with high hills where as sub-tropical to temperate pasture types were mostly observed in southern mid hills and in the valley of rivers in upper reaches.

Soil status

An intimate knowledge of the soil characteristics (physical and chemical composition) and their spatial distribution is required for developing, balancing and management of various land use activities or planning for pasture production programmes. Physical and chemical composition of the soil influence spectral signature of soils through the absorption processes. It is also influenced by the degree of the slope, ground cover and climatic conditions.

Table 2: Characteristics of the available nutrients in soil at different hill zone of Sikkim.

Hill Zones	GPS Point	BD (gm/cc²)	pH	EC (dsm⁻¹)	OC (%)	Available N (kg ha⁻¹)	Available P (kg ha⁻¹)	Available K (kg ha⁻¹)
Mid Hill	G1	1.14	5.25	0.09	1.49	517.10	16.35	136.62
	G2	1.24	5.94	0.12	0.95	319.60	10.39	103.65
	G3	0.83	4.89	0.29	1.25	519.90	23.09	161.89
	G4	0.88	5.20	0.23	1.82	602.70	21.14	199.60
	G5	1.00	6.34	0.26	1.99	536.60	21.28	198.46
	G6	1.04	5.25	0.25	1.52	503.50	18.30	201.54
	G7	0.69	4.14	0.29	2.04	600.80	20.21	387.80
	Average	0.97	5.29	0.22	1.58	514.31	18.68	198.51
High Hill	G8	0.79	4.84	0.29	2.25	922.30	24.21	407.30
	G9	0.75	5.13	0.30	2.01	810.10	23.14	133.60
	G10	0.91	5.71	0.15	2.21	932.10	25.04	201.70
	G11	0.99	5.55	0.15	2.02	916.30	22.81	145.19
	G12	0.84	5.83	0.31	2.61	1031.40	24.62	251.01
	G13	0.89	5.19	0.21	2.13	962.50	23.64	128.46
	G14	0.94	5.25	0.16	2.41	1113.90	29.06	129.77
	Average	0.87	5.36	0.22	2.23	955.51	24.65	199.58

Table 3: Grasslands area under different hill zones of Sikkim.

Hill Zones	Geographical Area (km2)	Geographical Area (%)	Grasslands (km2)	Percentage of Grasslands under different hill zone	Percentage of Total Grasslands
Mid	3336.70	47.02	479.34	14.37	6.76
High	3759.30	52.98	523.36	13.92	7.38
Total	7096.00	100.00	1002.70	14.13	14.13

With the help of satellite images and GPS, 14 soil sampling sites, located at different altitudes (1045 to 4065m) in high hills zone (7 sites) and mid hills zone (7 sites), were selected for the sampling. Soil samples (upto 15cm depth) were taken from 5 places from each site and finally the analyzed data were pooled for each soil sample sites. Approximately, 500gm of the each soil sample were used for laboratory analysis such as the pH, Nitrogen (N), Potassium (K), Phosphorus (P) as plants need in specific amounts to grow, thrive, and fight off diseases, Bulk Density (BD), Electrical Conductivity (EC) and Organic Carbon (OC).

The study reveals that the percent organic carbon (OC) was low in mid hill zones (0.95 – 2.81 %) whereas it was high in high hill zone (2.00 – 2.61 %). The increase in the organic matter content may be directly related to increase in altitude (Table 2). The pH of soil was 4.84 to 5.83 at various altitudes of high hill zone and from 4.14 to 6.34 in mid hill zone, which show the acidic nature and variation of soil in the state. Electrical conductivity (EC) of the soil ranged from 0.15 to 0.31 dsm^{-1} in high hill zone and 0.09 to 0.28 dsm^{-1} in mid hill zones. Bulk Density (BD) of the soil ranged from 0.79 to 0.99 gm/cc in high hill zone and 0.69 to 1.2 gm/cc in mid hills. The available nutrients in the soil, mainly nitrogen content (N) varied from 810.1 to 1113.9 Kg ha^{-1} in high hill zone and between 319.6 to 1402.7 Kg ha^{-1} in mid hill zone. The available phosphorus (P) content of the soils varied from 22.81 to 29.06 Kg ha^{-1} in high hill zone and 10.39 to 24.14 Kg ha^{-1} in mid hill zone. The available potassium (K) content of the soils varied from 133.60 to 407.30 Kg ha^{-1} in high hill zone and 103.65 to 599.60 Kg ha^{-1} in mid hill zone. There were no much difference in average EC (0.22 dsm^{-1}) and K (198.51 - 199.58 kg ha^{-1}) in both the hill zones whereas the average pH (5.36), OC (2.23 %), N (955.51 kg ha^{-1}) and P (24.65 kg ha^{-1}) was found high in high hill zones. The fertility status, density and depths alongwith the nitch conditions directly influences the productivity and sustainability of pasturelands in different elevation zones in Sikkim.

Pastures status

Spatial data layers were used to understand the sustainability and production of temperate / alpine pastures by selecting data with the appropriate spatial resolution (Fig. 2). Assessment of pasture lands were

carried out using LISS-III imagery of IRS-P6 and GPS supported intensive ground truthing (GT). ArcGIS version 10.x was used for geo-processing work. The study reveals that about 14.13 % area is under pasture lands. Though, about 34% area of pasture land falls under the control of forest department and private owners where the production and its utilization patter is different. The area under alpine pastures in high hill zone was about 7.38 % of total geographical area of Sikkim (Fig 4) whereas it was 6.76% (Fig 3) in mid hills (Table.3).

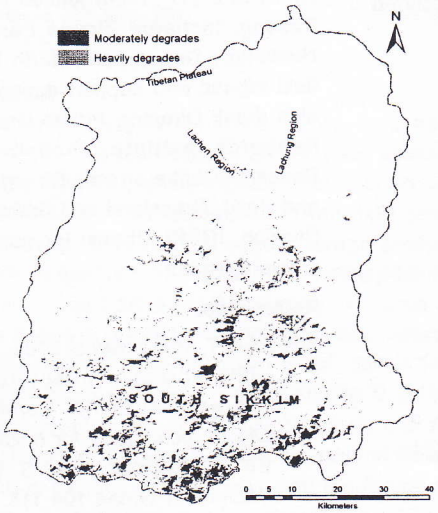

Fig.3: Mid hill Pastures in Sikkim

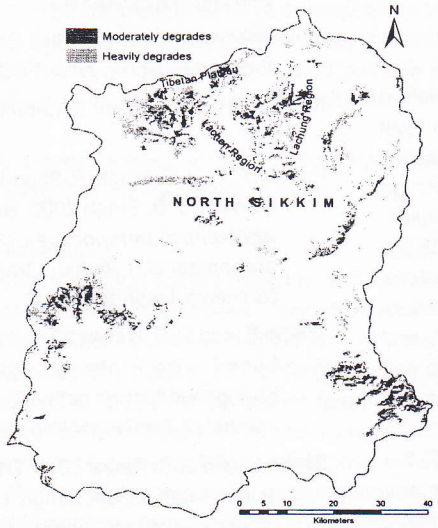

Fig.4: High hill Pastures in Sikkim

The major differences in the extent of pasture lands in both zones were polygon size and shapes. It is clearly evident from the figures 4 and 5 that the shape of pasturelands in mid hills was linear, narrow and along the slopes whereas these appeared mostly wide and irregular hexagonal and covers fringe area of snow caped uplands. IRS-P6-LIII image clearly provides the information on degradation of existing pasture lands. About 43.65 % pasture land located in mid hill were at various stages of degradation due to landslide, soil erosion/depletion and loss of soil nutrients. The condition of pasture lands (Fig. 5) located in high hill was relatively better as percentage of degraded pasture land was only 32.88 though altitude was recorded more (2500-4500m) but relief was relatively low (<400m) and much of the healthy alpine pasture was located on hill top and side slopes. Alpine grasses and sedges had uniformly very high fiber content (Tambe and Rawat, 2009). The CP content ranged from 8.5 to 19.5 percent from mid hill to high hill whereas average forage production from natural pasturelands was recorded high (0.85 – 3.25 tDM/ha) in mid hill than high hill (0.31 – 2.45 tDM/ha). It was directly related to the soil health (Fig.6) of pastures land located in both hill zones.

Fig. 5 Pasture lands at different altitude in Sikkim

Different types of grasses, legumes and scrub species were found in Sikkim. *Juniperus squamata*, *Juniperus indica*, *Rhododendron*, *Morainic* were mainly seen in the glaciated valleys along the lateral and terminal moraines. Species like *Riverine willow* (*Salix sikkimensis*) and *Riverine (M. rosea)* were usually found in the upland valleys whereas *Kobresia nepalensis* (moist meadows), appeared as dense soft mat-like formation having an average height of 0.1 m, on smooth slopes and ridge tops in the upper reaches of moist and exposed glaciated valleys.

Important moist meadows like *Kobresia duthiei* was found in shady moist valleys and rocky slopes whereas *Kobresia pygmaea* (dry meadows), having an average height of 0.05 m, was found in the upper reaches of the glaciated and relatively dry valleys of Zemu and Lhonak. Tambe and Rawat (2010) have also reported that *D. caespitosa,* marsh meadows, mainly occurred in the form of tussock on waterlogged flats adjacent to alpine lakes and in the upper courses of meandering streams. The top height of *D. caespitosa* was upto 1 meter. Species like *Anaphalis xylorhiza (*mixed meadows) normally occurred in the inner valleys on the glaciated flats.

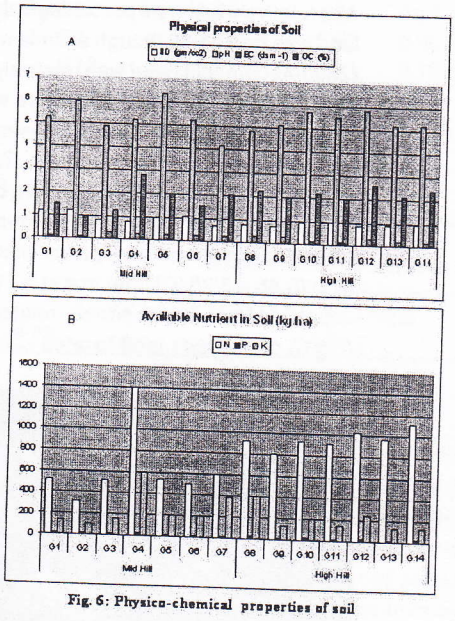

Fig. 6: Physico-chemical properties of soil

Conclusions

Geo-spatial information supported with GPS linked ground data on shape, size, extant and production level of pasture lands located in different elevation zones, soil health and landform features provide accurate knowledge base for the restoration of temperate/ alpine pasture lands. It is evident from the study that at present about 36.5% area of the total pasture lands (14.13% of the total geographical area) were at various stages of degradation. Pasture lands (43.65%) located at different altitudes and slopes in mid hill zones were more susceptible to soil erosion/ depletion and landslides. Landform features and soil status (pH, N, P& K) also influences the forage production (0.31 – 3.25 t DM/ha) and CP content (8.5 – 19.5) in different hill zones. Geomorphic processes and resultant topography along with soil fertility status broadly determined the sustainability of forage production, area and shape of these temperate/ alpine pasturelands.

Human induced factors (utilization pattern) and grazing pressure also influenced the sustainability of pasturelands. For the amelioration of these pasture lands, site specific restoration / management plan supported with Geomatic tools could be designed for their sustainable production.

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