

**ETATION DYNAMICS AND LAND USE COVER
OF 'Ga3a' MICRO-WATERSHED OF GIRI
RIVER IN SOLAN DISTRICT OF HIMACHAL
PRADESH, INDIA**

Thesis

by

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*Submitted in partial fulfilment of the requirements
for the degree of*

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(SILVICULTURE)



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CERTIFICATE-I

This is to certify that the thesis entitled “**Vegetation dynamics and land use cover of ‘Ga3a’ micro-watershed of Giri River in Solan District of Himachal Pradesh, India.**”, submitted in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE in FORESTRY (SILVICULTURE)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan (HP) is a bonafide research work carried out by **Mr. Haseeb ul Rashid Masoodi (F-2007-23-M)** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

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Dated: 31 March, 2010

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This is to certify that the thesis entitled “**Vegetation dynamics and land use cover of ‘Ga3a’ micro-watershed of Giri River in Solan District of Himachal Pradesh, India.**”, submitted by **Mr. Haseeb ul Rashid Masoodi (F-2007-23-M)** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan (HP), in partial fulfilment of the requirements for the award of degree of **MASTER OF SCIENCE in FORESTRY (SILVICULTURE)** has been approved by the Student’s Advisory Committee after an oral examination of the same in collaboration with the external examiner.

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(Haseeb ul Rashid Masoodi)

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ABBREVIATION

Anon	:	Anonymous
&	:	And
C	:	Carbon
CD	:	Critical Difference
cm	:	Centimeter
cm ²	:	Centimeter square
CO ₂	:	Carbon dioxide
D	:	Diameter
DEM	:	Digital Elevation Model
E	:	East
et al	:	And Coworkers
etc	:	Extra
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
FRI	:	Forest Research Institute
FSI	:	Forest Survey of India
g	:	Gram
g cm ⁻³	:	Gram per Centimeter Cube
GIS	:	Geographical Information System
GS	:	Growing stock
ha	:	Hectare
ha ⁻¹	:	Per hectare
HH	:	House Hold
i.e.	:	That is
IPCC	:	Intergovernmental Panel on Climate Change
IVI	:	Important Value Index
kg	:	Kilogram
km ²	:	Kilometer square
m	:	Meter
M ha	:	Million hectare
m ²	:	Meter square
Mg	:	Mega gram

mm	:	Milli meter
Mm ³	:	Million cubic meter
Mt	:	Metric tones
N	:	North
NE	:	North-East
NW	:	North-West
°C	:	Degree Celsius
OC	:	Organic Carbon
%	:	Percent
Pg	:	Petagram
RS	:	Remote Sensing
SE	:	Standard Error
SE	:	South-East
SOC	:	Soil Organic Carbon
SW	:	South-West
t C ha ⁻¹	:	Tonnes Carbon per hectare
t ha ⁻¹	:	Tonnes per hectare
t/ha	:	Tonnes per hectare
Tg ha ⁻¹	:	Tera gram per hectare
TIN	:	Triangulated Integrated Network
TM	:	Thematic Maps
V	:	Volume
Viz.	:	Such as
Yr	:	Year

Chapter-1

INTRODUCTION

Every parcel of land on the Earth's surface is unique in the cover it possesses. Land use and land cover are distinct yet closely linked characteristics of the Earth's surface. The use to which we put land could be grazing, agriculture, urban development, logging, and mining among many others. While land cover categories could be cropland, forest, wetland, pasture, roads, urban areas among others. The term land cover originally referred to the kind and state of vegetation, such as forest or grass cover but it has broadened in subsequent usage to include other thing such as human structures, soil type, biodiversity, surface and ground water (Meyer, 1995). Land cover can be altered by forces other than anthropogenic. Natural events such as weather, flooding, fire, climate fluctuations, and ecosystem dynamics may also initiate modifications upon land cover. Globally, land cover today is altered principally by direct human use: agriculture, livestock raising, deforestation and urban development. Hence, in order to use land optimally, it is not only necessary to have the information on existing land use /land cover but also the capability to monitor the dynamics of land use resulting out of both changing demands of increasing population and forces of nature acting to shape the landscape.

The growing global concern for conservation of the world's natural resources has resulted in the formulation of long-term perspective plans for conserving natural resources especially forests. These forests facilitate the conservation of ecological balances, biodiversity, enhance the quality of environment by checking soil erosion, water retention and conservation, regulate water cycle, act as a carbon sink which balances the carbon dioxide and oxygen in the atmosphere and facilitate in reduction of the greenhouse gases effect etc. Population pressure,

poverty and weak institutional framework have often been viewed as the predominant underlying causes of forest depletion and degradation. Excessive population and livestock pressure and the requirements of forest products for essential development generate a pressure on forest resources like fuelwood, fodder, timber, lumber, paper etc., which in turn triggers a deforestation process. Overexploitation of the forests resources as compared to its incremental and regenerative capacities escalates the forest depletion and degradation process.

Himachal Pradesh is a part of the northern ranges of Himalayas, where greater and middle Himalayas are covered with snow or devoid of any soil and the outer Himalayas (Shivaliks) are characterised by steep slopes, torrential rains, fragile ecology and rapid deforestation (Yadav, 2006). Increasing population pressure and inappropriate economic policies are further deteriorating the sustainability of natural resources. Declining forest density in Himachal Pradesh in the recent past has become a cause of concern for the policy makers as well as for the environmentalists (FSI, 2003). While total biomass productivity exceeds human and animal consumption by a wide margin, there is a progressive loss in forest cover (Moench and Bandyopadhyay, 1986). Simultaneously, changing land use and cropping patterns have evolved with integration of commercial horticultural crops (Sharma *et al.*, 2007; Singh, 1999). Growing area under horticultural cash crops over the last few years has put increased pressure on forest resources through land clearing, declining agricultural residues and increased demand of production and marketing risks. The environmental consequences for the local communities cannot be ignored and requires immediate attention by the policy makers.

Land cover and its variation in time and space is a function of social set up and human interventions on the landscape. In the Himalayan region, in addition to these factors, topography is an important factor for describing land use. In spite of the most sensitive region in terms of its

natural environment, stability and complexity, the land cover changes are in accelerating rate because of high dependency of population on natural resources for their livelihood. The vastness and difficult terrain of these areas poses serious limitations on ground observation, consequently field experimentation and information collection to understand system dynamics and their relations to topography and social set up. Analysis of land cover dynamics has been attempted using GIS overlay function by comparing time series maps prepared from satellite remote sensing data by many workers (Hui, 2004; Martin and Saha, 2009). Assessment and monitoring of forest vegetation land use changes have greatly been facilitated with the advancement of optical satellite remote sensing technology (Sader *et al.*, 1985). With the passage of time more number of studies has been generated in this field by using the aerial photographs, Landsat TM and Indian Remote sensing satellite data (Pant and Singh, 1992; Pant and Roy, 1995).

With the launch of a numbers of Indian and International Remote sensing satellite, it has become easier and quicker to acquire high resolution image and data on the coverage, which import knowledge about conditions on the earth surface that changes in a landscape over time. This is an important utility of RS-GIS which emphasizes on spatial and non spatial attributes. Through GIS different features of an area can be reflected by thematic maps. Combining these thematic layers under GIS using a set of logical conditions land use pattern of each watershed can be generated. Thus, remote sensing and GIS has proved to be an effective tool.

Biomass assessment is important for many purposes (Parresol, 1999; Zheng *et al.*, 2004). It provides information on resource use and environmental management. It is important to determine how much fuel wood or timber is available for use. In the light of environmental management, biomass assessment is important to assess the productivity and sustainability of the forest. Biomass is also an important indicator in

carbon sequestration. For this purpose one needs to know how much biomass will be lost or accumulated over time. Consequently, the amount of carbon sequestered can be inferred from the biomass change since 50% of the forest dry biomass can be inferred as carbon (Losi *et al.*, 2005). Change in forest biomass (or carbon fluxes) are influenced by natural succession, anthropogenic actions such as deforestation, harvesting, plantation, silviculture and natural disturbances by pests, fire and climate change (Brown, 1997; IPCC, 2006; Schroeder *et al.*, 1997).

Emphasis has been laid since long on the need for integrated catchment management and impact of landuse on catchment hydrology. Impacts of landuse change are even more critical in developing countries where development pressures on river basins are high; but the two disciplines have not been amalgamated for creating catchment sensitive 'Landuse plans' (Tandon, 2007).

Socioeconomic information of any area is useful in identifying the complex integration between people and their environment. To combine socioeconomic informations with biophysical dimensions of any area GIS is an useful tool (Grove and Hohmann, 1992).

The present work thus has been undertaken with a view to ascertain socio-economic and vegetation diversity in Giri watershed of Himachal Pradesh. The study generates scientific database for "Ga3a" micro-watershed with the following objectives:

- i) To delineate land use pattern
- ii) To study socio-economic status of the inhabitants
- iii) To determine the carbon stock of vegetation

Chapter-2

REVIEW OF LITERATURE

Recent literature pertaining to the various aspects of present investigation has been reviewed as under:

Singh *et al.* (1975) opined that floristic composition of grasses varies with altitude. They have reported grasses like, *Heteropogon contortus*, *Arundinella camus*, *Bothriochloa pertusa*, *Chrysopogon gryllus* at 2360 m altitude and *Arundinella nepalensis* and *Agrostis canina*, *A. stolonifera*, *Festuca gigantea*, *Dactylis glomerata* at 2915m in grasslands of Himachal Pradesh. Sundriyal *et al.* (1987) also reported variations in floristic composition of grasslands along altitude in Garhwal Himalaya. They argued that grazing cutting and burning has long term effects on species composition. Noor Mohammad (1989) noticed that ground flora varies with the degree of canopy opening, the amount of needle cover, soil depth and height condition.

Gill (1975), Singh and Yadava (1974) and Singh and Joshi (1979) reported that variations in floristic composition of herbage vary with climate and abiotic stresses. Rainfall of an area is the major factor which governs the dominance, growth, structure and floristic composition (George and Vergease, 1985). Park *et al.* (1986) reported that more than 25 per cent shade markedly reduce the number of tillers in grasses and suggested that biotic and abiotic stresses may result in loss of some species and reduce resilience of ecosystem. Igboenugo *et al.* (1986) reported that with an increase in light intensity there is simultaneous increase in diversity of plants. Low species richness and diversity in chir pine forests is reported by Singh and Singh (1987). Sibbald *et al.* (1991) reported strong allometric relationship between green crown area of trees & relative pasture production. They contended that evergreen conifers reduce herbage production due to shade effect.

Basnyet (1989) studied the land use of Kankani panchayat located in north-west of Kathmandu valley in the mid hills of Nepal and classified it into outward terrace, forest, flat terrace, scrub, crop, gullies & pasture and estimated the percentage to the total geographical area under each as 37.1, 36.9, 12.8, 5.6, 5.4 and 2.2, respectively. Kulbhushan (1989) studied land use types and their erosion behaviour in Kinnaur great Himalaya. He has reported the following land uses viz., cultivated area, fallow land, grassland, culturable wasteland, forest, alpine pasture and miscellaneous and found maximum area (41.24%) under alpine pasture followed by miscellaneous (34.97%).

Biomass production is reflection of diversity of species and their adaptation to the prevailing environment. Saha and Saxena (1990) recorded 90 per cent contribution of grasses and sedges to the aboveground biomass under *Quercus leucotrichophora*. Further, they reported that *Themeda anathera* contributed around 50 per cent to the aboveground biomass under *Pinus roxburghii*. Melkania (1991) observed that grasses contributed about 93.3 per cent of the aboveground biomass in *Pinus roxburghii* plantations with *Heteropogon contortus* being the dominant grass.

Callaway *et al.* (1991) contended that trees may suppress or enhance productivity of understorey grasses dominated by *Avena fatua*, *Bromus mollis* and *B. diandrus* under blue oak (*Quercus douglasii*) trees in Santa Lucia Mountain in central California. They opined that grass productivity is facilitated under blue oak by nutrient input through litterfall. Belsky *et al.* (1993) observed unique understorey floral composition under tree crown zones at highly and moderately grazed sites. They recorded higher plant biomass and lower temperature under tree crowns than in the associated open grasslands. East and Felker (1993) stated that tree canopy is a major constraint in the productivity of herbaceous vegetation which reduces the rate of transpiration, leaf temperature and stomatal

conductance of grasses growing under tree canopy that reduces the biomass production.

The soil is the largest terrestrial pool of organic carbon, with global estimates ranging from 1115 to 2200 Pg of C (Batjes, 1992) or 1576 Pg of C (Eswaran *et al.*, 1995) or 1220 Pg of C (Sombroek *et al.*, 1993). Litter is not included in the calculation of soil organic carbon mass (Sombroek *et al.*, 1993), although amounts of carbon stored in the litter layers of many virgin and forested soils can be considerable.

Gupta (1996) investigated Landsat TM satellite data for Shimla district (H.P.) and recorded land cover types viz., agriculture, mixed alpine, fir-spruce, oak, deodar-fir-spruce, grassland, broad leaved pine and snow. He reported minimum area (4.63%) under fir-spruce-deodar and maximum area under miscellaneous tree species and snow cover. Kumar (1999) classified the land use of Moul khad catchment in sub-humid mid-hill zone of Himachal Pradesh into cultivated, forest, scrub land, degraded grassland, built up and river bed. The area under each land use class was estimated to be 38.6, 29.4, 8.3, 9.8, 13.4 and 0.5 per cent, respectively. Adinarayana and Krishna (1996) classified the hilly watershed in the western ghats of India (Maharashtra) through GIS into thick forest, sparse forest, degraded pastures, open areas, cropped and fallow lands. Ghosh *et al.* (1997) studied land uses of Pranmati watershed in Garhwal Himalaya using GIS and delineated land use types viz., cultivated, pastures, forests, degraded forests, bare rock and alpine meadow. The per cent area under each category was: 18.74, 2.00, 65.00, 6.90, 6.63 and 5.53, respectively.

Bargali *et al.* (1998) studied the effect of forest cover on certain sites and soil characteristics in Kumaun Himalayas. They observed that organic carbon was higher under Tilonj oak (*Quercus floribunda*) followed by Banj oak (*Q. leucotrichophora*) than deodar and lowest in chir pine forest. While bulk density of soil showed a reverse pattern. They also observed that oak forest had better soil conditions than conifer forest. Low

density and basal area of grasses under chir pine in sub-tropical region of Himachal Pradesh have been reported by Guleria (1996), Dalai (1997), Rao (1998), Dass (1995), Dutt (1999) and Gupta *et al.* (2000). They have also reported less herbage production under chir pine stands as compared to pure grassland.

Jitendra *et al.* (2001) studied the phytosociological parameters in three and six year's old *Acacia auriculiformis* plantations and reported more species and higher density of vegetation in three years old plantation. Soni (2001) studied the floristic and productivity variation among different tree based silvipastoral system vis-à-vis open grassland in temperate region and reported higher density and basal area of herbage species in open grassland as compared to sivipastoral systems. Gupta *et al.* (2002) argued that in silvipastoral systems reduced illumination under trees affected tiller formation and biomass production of the grasslands. They recorded plant species like, *Apluda mutica*, *Chrysopogon montanus*, *Themeda anathera*, *Heteropogon contortus*, *Dichanthium annulatum*, *Panicum maximum*, *Cyperus rotundus*, *Lespedeza gerardiana* and *Micromeria biflora* in different silvipastoral systems. The study also revealed that basal area and biomass of herbage was highest in the open grasslands. Ludwig *et al.* (2004) reported completely different herbage species under *Acacia tortilis* trees in comparison to vegetation in open grassland.

Sharma and Sharma (2002) studied land uses of Kawal watershed in H.P using remote sensing and GIS. They suggested that steep slopes, scrub and barren lands are more susceptible to soil erosion and should be treated on priority basis to prevent the degradation of land. Sah (2002) studied land uses and productivity of different grasslands in Kawal watershed of Himachal Pradesh. He reported the land uses viz., dense forest, sparse forest, open scrub, cultivated land, grassland, habitation and rock out crop. He also reported maximum species in grasslands and oak based grasslands.

Khanduri *et al.* (2002) conducted an investigation of forest composition in relation to socio-economic status of people in three villages at elevation of 1700m (Makkumath), 1900m (Krokhi) and 2100m (Sari) in Kedarnath Forest Division, Garhwal Himalaya. The average fuel wood consumption per household ranged from 9.73 Kg/day at Sari to 4.94 kg/day at Makkumath. Fodder consumption from forest per cattle was maximum at Makkumath (6.76 ± 0.46 Kg/day) and minimum in Sari (5.74 ± 0.57 Kg/day). Bahar (2003) during his study on phytosociology and biomass production of undergrowth vegetation in *Eucalyptus tereticornis* in Uttarakhand reported maximum biomass production of undergrowth vegetation in rainy season and minimum during summer.

Chauhan *et al.* (2004) compared carbon stock in plant communities viz., pure pine, pine–*Michelia champaca*, mixed pine, pure *Cinnamomum camphora* at FRI Dehra dun and observed maximum carbon stock in mixed pine community followed by pine-*M. champaca*, pure pine and pure *C. camphora*. Gautam *et.al.* (2004) studied changes in forest cover in a mountain watershed in central Nepal from 1976 to 2000 by comparing classified satellite images coupled by GIS analysis and examined the association of forest change with major physiographic, economic and local forest governance parameters and found increase in forested area (forest plus shrublands) by 7.6% from 1976 to 2000.

Debashis *et al.* (2004) developed remote sensing-based health index after analyzing the change in land use and vegetation vigour. Both vegetation vigour and land use types were rated on the best possible use of the land and maximum benefit expected of a given soil and water conservation treatment. Seven land use/land cover types were identified in the watershed i.e. crop area, fallow area, forest, land with and without scrub, sandy area and water body. Joshi *et al.* (2004) studied land cover dynamics vis-à-vis topography in Huniyal watershed in Garhwal Himalaya using satellite data of 2001 and 1986. They identified 31 classes of land cover by giving different tone colour to *Cedrus deodara* forest, oak forest, oak mixed forest, *Pinus roxburghii* forest, pine oak mixed forest, pine

mixed forest, mixed forest, *Shorea robusta* forest, *S. robusta* mixed forest, forest plantation, river line forest, roads and riverbeds. They estimated distribution of these forests in watershed and found that forest cover has changed throughout the watershed but was more near human settlements. They suggested that valley areas were devoid of forests and require immediate attention to take suitable measures for afforestation activities.

The natural forest-stands of any place are the result of the interaction of various factors of the soil and the environment (Kumar *et al.*, 2004). They further opined that the quantum of biomass produced over a period of time depends largely on the nature, aggregation of species and the nutrient supply potential of the soil. On the other hand, the forests also have a marked influence on the structure of the soil. Manhas *et al.* (2006) estimated biomass, wood (stem) biomass, growing stock (GS) and carbon stock of Indian forests from 1984 to 1994. The forest area, wood biomass, GS, and carbon stock were 63.86 Mha, 4327.99 Mm³, 2398.19 Mt and 1085.06 Mt, respectively in 1984 and with the reduction of forest area to 63.34 Mha in 1994. There was a significant reduction in wood biomass (2395.12 Mt) and carbon stock (1083.69 Mt) in 1994. The conifers of temperate region stocked maximum carbon in their woods (28.88 to 65.21 t C ha⁻¹) followed by mangrove forests (28.24 t C ha⁻¹), dipterocarp forests (28.00 t C ha⁻¹) and *Shorea robusta* forests (24.07 t C ha⁻¹). The order of carbon stocked in major forests decreased in the order: Miscellaneous forest > *Shorea robusta* forest > *Tectona grandis* forest > Temperate forest > Tropical forest > Tropical forest > Bamboo forest etc. The average C stock in the country was estimated to be 24.94 t C ha⁻¹ in the year 1984 and 24.54 t C ha⁻¹ in 1994.

Dass and Gupta (2005) reported low species composition accompanied by less herbage production under chir pine stands as compared to pure grassland in North-West Himalaya. Arunachalam and Arunachalam (2005) reported that species diversity index has linear relationship with litter, fine roots and microbial biomass accumulation in

the broad-leaved forest re-growth while, density and basal area were negatively correlated to these functional processes in pine trees.

Semwal *et al.* (2005) reported coal mining as the root cause of changes in land use and land cover types in Jaintia Hills. The overall rate of change was found as 2.16% per year. This includes 0.1% per year change due to coalmines. The agricultural land was reduced by 26.40 Km² or 22.35% of its total area and the lands were transformed into coal mines, habitation related to coal mines and the abandoned agricultural land classified as grassland/scrub.

Jain *et al.* (2005) conducted studies on the analysis of vegetation and land use change in khecheopalri sacred lake watershed and concluded that the anthropogenic pressure has led to land use/cover change of the watershed in the past decade with increase of agricultural land at the expense of forests. The pressure of grazing was also high resulting in removal of 47% of annual primary production of floor phytomass. Dutt and Gupta (2005) reported considerable variations in herbage production under chir pine stands in sub-tropical region in India. Herbage biomass and LAI considerably increased from July to August/September and thereafter showed a continuous decrease up to November. Among different species *Themeda anathera*, *Panicum maximum*, *Chrysopogon montanus* and *Pollinia argentea* were found to be the major contributors to the biomass production. Also, values of biomass production and LAI of herbage were higher in grasslands as compared to chir pine inhabited sites.

Organic matter in the soil are regulated essentially by net primary production, the distribution of assimilates into 'roots' and 'shoots', and the rate at which various organic compounds decompose. Plant residues (litter) that fall on the soil are gradually altered through physical fragmentation, faunal and micro floral interactions, mineralization and humus formation. It has long been established, especially since the Rio Summit in 1992 that temperature, soil temperature, rainfall, soil texture,

pH and type of vegetation or land cover are the major factors controlling the level of soil organic carbon (Krishnan *et al.*, 2007).

Thapa (2007) contended that remote sensing technique using aerial and space based sensors is effective for efficient and faster resource mapping. This information on integration with the field observation generates accurate set of data that is used to produce set of thematic maps with GIS (Geographic Information System). Different layers are utilized to bring all the information from all possible sources into a common platform for decision making and database modeling. This GIS based data analysis has been found to be most effective tool for land use assessment and is easily accessible to the users.

Singh *et al.* (2007) studied land uses in Nagin watershed of Uttarakhand using GIS and remote sensing and observed that the agricultural area had reduced from 66.71 to 32.75% over a period of 42 years. At the same time, 13.51% area revealed that the forest area increased by approximately 100% including both dense and moderately dense forest. Ramachandran *et al.* (2007) used geospatial technology to estimate total above and below ground biomass carbon stock in Kolli hills of Eastern Ghats of Tamil Nadu. They estimated 2.74 Tg, of carbon in semi-evergreen forest, deciduous forest and other forests which contributed 22%, 57% and 21% of carbon, respectively to the total pool. Vegetation biomass carbon density in semi-evergreen forests, deciduous forests, secondary deciduous forests, thorn forests and *Euphorbia* forests was 0.60 Tg ha⁻¹, 1.57 Tg ha⁻¹, 0.35 Tg ha⁻¹, 0.22 Tg ha⁻¹ and 0.01 Tg ha⁻¹, respectively, which was similar to the average carbon density of the tropical forests whereas, the average biomass carbon density recorded in tropical degraded forests was from 63.33 to 156 t ha⁻¹.

Tiwarly *et al.* (2008) studied land use and biomass in Khanda watershed, Garhwal Himalaya using remote sensing data. They recorded the total above ground biomass of oak forest, mixed oak forest and *P. roxburghii* forest as 272.87 t/ha, 259.28 t/ha and 174.16 t/ha, respectively.

Singh (2008) investigated carbon sequestration along altitudinal gradient in sub-tropical pine forests in Solan Forest Division of H.P. The study revealed that carbon stock was recorded maximum in broadleaved land use followed by ban oak, deodar, chir pine, cultural and unculturable land use. He reported that carbon stock increased with increase in elevation.

Chandra *et al.* (2008) studied fuelwood, fodder and livestock population in Arnigad watershed of Mussoorie hills (Uttarakhand) and reported that the fuelwood species used here were: *Thysanolaena maxima*, *Bauhinia retusa*, *Grewia optiva*, *Quercus leucotrichophora*, *Flacourtia ramontchii*, *Ougeinia oogeinensis*, *Celtis australis*, *Bauhinia vahlii*, *Lantana camara*, *Woodfordia fruticosa*, *Mangifera indica*, *Butea monosperma* and *Syzigium cumini*. Whereas fodder species were: *Murraya koenigii*, *Flacourtia ramontchii*, *Celtis australis*, *Bauhinia vahlii*, *Q. leucotrichophora*, *W. fruticosa*, *Chrysopogon fulvus* and *Apluda mutica*. Further, dense forest was the major sources of fuelwood i.e. 44.44% followed by Scrub forest 36.50%, degraded land 13.09% and cultivated land 5.95%. Fodder collection (%) was most from dense forest 37.27% followed by scrub forest 32.63% and least from cultivated land 14.22%.

Singh *et al.* (2008) studied the socio-economic profile of Indian desert. The average land holding varied from 5-35 acres. The overall human density in the area was 38 persons per km². The average literacy rate was 38.5%. While, average fodder and fuelwood consumption was 9.87 kg/livestock and 10 kg/day, respectively. Ratio of livestock to human population was 1.5.

The study conducted by Minj (2008) in low & mid hills of western Himalaya during year 2004-06 revealed that mean biomass carbon stock & CO₂ sequestration in Zone-I (sub montane low hills) was 2.09 times higher than Zone-II (mid hills). Maximum mean total carbon stock (107.00 t ha⁻¹) was observed in pure plantations of poplar with average density of 1066 trees/hectare. It was 2.68-4.86 times higher than other perennial

plant based systems and about 12.40-22.57 times higher than annual crops or pure grassland system.

Rattan and Singh (2009) studied the floristic diversity of woody perennials in Katola range of Mandi Forest Division (H.P.) and reported that 17 floral families contributed to the 27 species with 62.96% and 37.04% trees and shrubs, respectively. The dominant and co-dominant trees and shrub species were: *Pinus roxburghii*, *Quercus leucotrichophora* and *Berberis aristata*, *Prinsepia utilis*, respectively. Distribution pattern of various tree species was contiguous except *Cedrus deodara*, *P. roxburghii* and *Myrica esculenta*, which were random while distribution pattern of shrub species was contiguous except *B. aristata*.

Chowdhary *et al.* (2009) studied integrated water resource development plan for sustainable management of Mayurakshi watershed in Dumka and Deoghar district of Jharkhand and reported that GIS with its capability of integration and analysis of spatial, multi-layered information obtained in wide variety of formats both from remote sensing and other conventional sources is an effective tool in planning for watershed development.

Benavides *et al.* (2009) reported that in silvipastoral system trees compete with pasture for soil resources and also cast shade on pasture that usually reduce productivity of pasture. However, trees can also alleviate extreme temperature reduce wind speed and evaporation from the site. Deciduous litter may contribute to increase pH and soil nutrient concentration but there is decline in pasture production and nutritive value under shade with increase in tree age and higher stand density. Gea-Izquierdo *et al.* (2009) studied the variability in annual grass production and composition induced by gradients of intercepted light by trees in years of contrasting precipitation in mediterranean helm-oak open woodlands. The presence of trees generally had a positive effect on pasture production in average climatic years when soil fertility was low but

the interaction changed with increasing abiotic water stress. They found that light insolation was positive for legume production.

Verma *et al.* (2009) studied composition of forest vegetation along an altitudinal gradient (400 m to 650 m) in Simbalwara wildlife sanctuary in which 53 tree species, 32 shrubs and 175 herbs were found. The plant communities identified at 400-525 m and 525-650 m elevation range were: *Shorea robusta* - *Mallotus philippensis* and *Shorea robusta* – *Terminalia alata*, respectively. On the basis of IVI, *Shorea robusta* was the dominant tree species at both the elevation ranges. Sharma (2009) studied the distribution of biomass in different land uses viz., chir pine, ban oak, deodar, other broadleaves, culturable and un culturable land uses, distributed in five Forest Ranges along altitudinal gradient from 900 to 2100m of Solan Forest Division (H.P.). The study revealed that out of 1.07 Mt of total biomass in the division, chir pine land use contributed 36.63%, ban oak 32.94%, deodar 1.15 % and culturable land 0.48 %. Along altitudinal gradient, it was 44.89% in 1500-1800m, 42.38% in 1200-1500m, 10.35% in 1800-2100m and 2.36% in 900-1200m elevation.

Nizami *et al.* (2009) estimated carbon stocks in sub-tropical pine (*P. roxburghii*) forests in two sites, Ghoragali and Lehterar, of Pakistan as 126 ± 2.94 and 99 ± 1.58 t/ha, respectively. Kaul *et al.*, (2009) studied the net carbon flux caused by deforestation and afforestation in India over the period from 1982 to 2002, separately for two time periods, 1982-1992 (PI) and 1992-2002 (PII) and reported that in the 1982-2002 period, the forest cover has changed from 64.20 Mha in 1982 to 63.96 and 67.83 Mha in 1992 and 2002, respectively. The average net flux of carbon attributable to land use change decreased from a source level of $5.65 \text{ Tg C yr}^{-1}$ (or $0.09 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$) during PI (1982-1992) to a sink level of $1.09 \text{ Tg C yr}^{-1}$ (or $0.02 \text{ MgC ha}^{-1} \text{ yr}^{-1}$) during PII (1992-2002). Over recent years, Indian forests have acted as a small carbon sink. The results indicate that the conversion of land to forest (regeneration/afforestation) led to a net uptake of 0.86 and $1.85 \text{ Tg C yr}^{-1}$ in PI and PII, respectively. The cumulative net carbon flux from Indian forests due to land use change

between 1982 and 2002 was estimated as 45.9 Tg C. The largest fluxes result from the conversion of forest land to cropland and waste lands.

Mahmoud (2009) evaluated the effect of different types of trees on herbage growth and recorded that there was a significant decrease in density, basal area and biomass of herbage under trees as compared to open grasslands and further, the density, basal area and biomass of herbage increased from June to August and it declined thereafter till October. The total biomass and carbon stock of vegetation under different systems at Solan H.P. was in order: *U. laevigata* > *Q. leucotrichophora* > *E. tereticornis* > *P. roxburghii* > mixed forest > *A. mollissima* > grassland (control)

Bulk density of soil decreases with the increase in organic matter content in soil (Goswami, 2009; Ramachandran *et al.*, 2007; Minj, 2008 and Singh, 2008). With an increase in soil depth the organic carbon content of soil also decreases whereas, the bulk density increase markedly (Malik, 1992; Kumar, 2003; Minj, 2008; Singh, 2008 and Goswami, 2009).

Chapter-3

MATERIALS AND METHODS

The present investigation entitled vegetation dynamics and land use cover of “Ga3a” micro-watershed of Giri river in Solan district of Himachal Pradesh, India was done during 2008-09. The physical and environmental attributes of study area, material used and methodology adopted for the study is given below.

Site description

Location

“Ga3a” micro-watershed is one of the 136 micro-watershed of Giri river, located in Solan district of Himachal Pradesh and lies between 30° 50' to 30° 53' N latitudes and 77° 08' to 77° 15' E longitudes. It covers an area of 2108 ha with the altitude variation from 900 m to 2040 m above mean sea level. This watershed lies in northeast part of Solan Forest Division. The Giri river is bounded by Himalayan mountain in north, Shiwalik ranges in south and lower Himalayas in southwest. Giri river is one of the tributaries to Yamuna river system.

Climate

Major portion of “Ga3a” micro watershed lies between humid sub-tropical. A little part of it supports sub-temperate climate. Meteorological observations taken in rainy season for the study area is presented in Fig.1. The area received monthly rainfall between 2.2 - 408.0mm with maximum rainfall in the month of September. Relative humidity during study period varied from 65% to 85%. Monthly mean maximum temperature ranged from 26.2°C to 29.0°C and mean monthly minimum temperature varied from 9.7°C to 19.5°C.

Physiography and soil

The geology of the micro-watershed reveals eocene rocks referred as Subathu formations, common rocks are rough slates, phyllites, mica schist, sandstone, limestone and quartzite. Soil on the upper reaches of the watershed is formed under coniferous vegetation that is rich in organic matter. In low areas of the micro-watershed soil is sandy loam with loose boulders and moderate water retaining capacity. The forest and pasture lands have better physical parameters, retention and infiltration of the water than cultivated lands (Chaudhary *et al.* 2002). "Ga3a" has sediment yield index of 1513 which comes under high priority category (All India Soil and Landuse Survey)

Forests

The micro-watershed area has sporadic vegetation representing sub-tropical to sub-temperate forests depending upon elevation. At lower elevation three forests viz., chir pine, ban-oak and mixed forest, were recognized and at middle elevation two forests viz., chir pine and mixed forest, whereas at higher elevation four forests viz., chir pine, ban-oak, mixed and deodar forest, were present.

Experiment No 1: To study the land use cover and socio-economic status of inhabitants in micro-watershed

Land use cover

Land use of the micro-watershed was determined by using topographic sheet No. 53 F/1 and stock map of Solan Forest Division (scale 1:50000). Contours on toposheet were digitized at 20m intervals (Fig. 2) using CARTALINX 2.1 and vector data so obtained was rasterized using IDRISI taiga to produce Digital Elevation Model (DEM) of the area (Fig. 3). It was reclassified into three elevation zones viz., lower elevation (900-1300m), middle elevation (1300-1600m), and higher elevation (1600m and above). Stock map available for the area was also digitized to

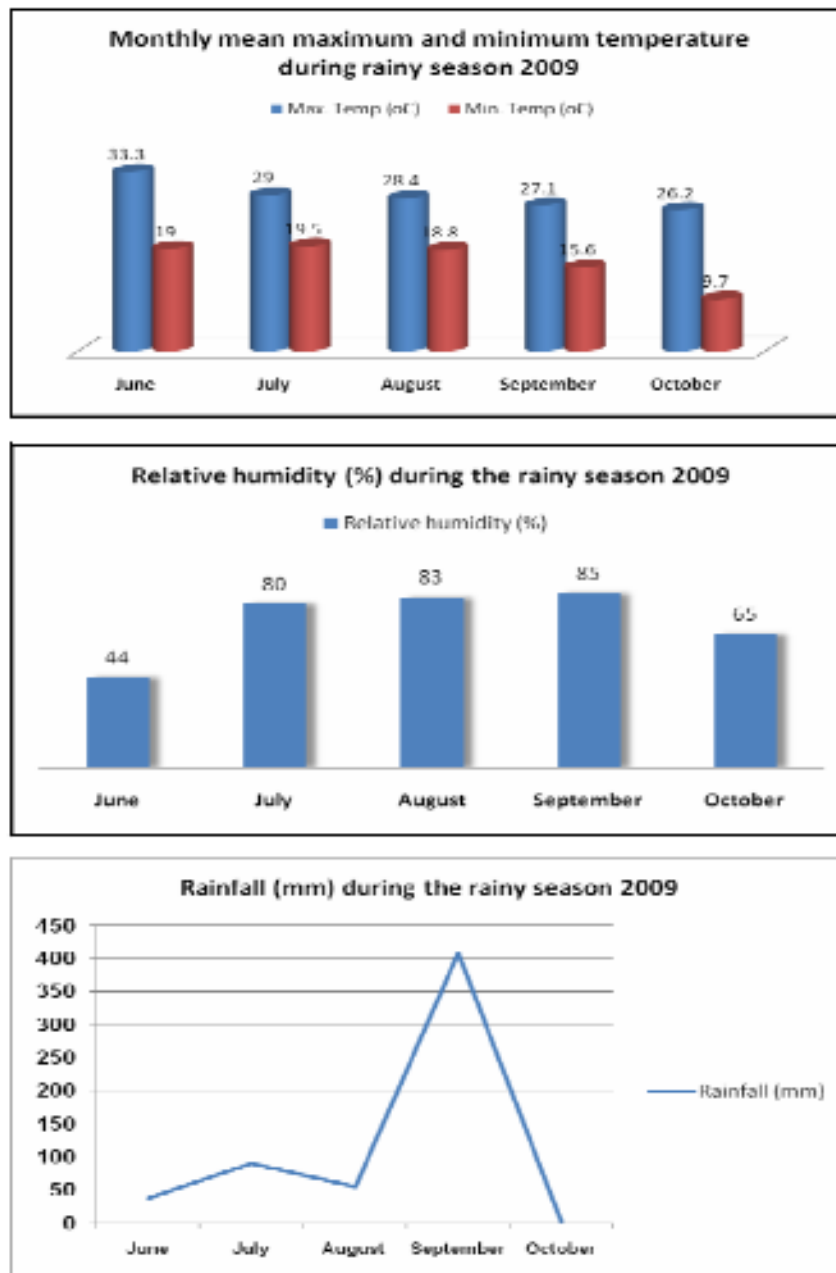


Fig. 1. Average monthly temperature, relative humidity and rainfall in the study sites

delineate various landuses and forest types at three elevations of the micro-watershed (Fig. 2).

Socio-economic status

Socio-economic data was acquired through field survey by doing proportionate random sampling of villages located at different elevation classes. The care was taken that the selected villages represent high, medium and low human population. A standard questionnaire (Annexure-I) was prepared to get the information on

- a) Families
- b) Land use pattern
- c) Forest resource use
- d) Agriculture
- e) Animal husbandry

Experiment No 2: To study vegetation dynamics and carbon stock in vegetation and soil

Vegetation analysis

Three sample plots of 0.1ha were marked in each forest at different elevation classes for analyzing structural and functional parameters of trees, shrubs and herbaceous vegetation. At each elevation three grassland sites of 20×20m were also selected adjacent to forests, to study their vegetation composition. In each sample plot one sub-plot of size 10×10m was marked to study shrub vegetation and two sub-plots of size 50×50cm was harvested to study herbaceous vegetation. Non destructive method was used to determine biomass of trees, whereas harvest method was used to determine biomass of shrubs and herbaceous vegetation. The basal area of each tree in the sample plot was determined by tree calliper and height was measured through relaskope. Stem volume of

trees was determined by using volume equations developed by forest research institute (FRI) Dehradun (Anon. 1996). Volume equation used for tree species were:

Deodar : $V=0.091531+0.294023 D^2 H$

Chir pine: $V=0.04529+0.284662 D^2 H$

Ban-oak : $\sqrt{V}=0.682380+5.049937D-2.770924 \sqrt{D}$

Where; V = Volume
D = Diameter
H = Height

Biomass of stem was calculated by multiplying volume with specific gravity of species, whereas aboveground biomass was obtained by biomass conversion factor (Jenkins *et al.* 2003) and belowground biomass as per IPCC, 2006.

Likewise through stratified sampling basal area of individual species of shrubs was determined by vernier calliper. Fresh weight of stem, leaves and branch was determined by taking weight at time of harvesting. Samples of stem wood, branch wood and leaves were brought to laboratory, dried in oven at 80°C for 72 hrs to determine dry weight. Below ground biomass was determined by extracting roots of selected shrubs, dried in oven and weighed.

Individuals of each species of herbaceous vegetation from different quadrates were counted separately and their basal area was calculated following Phillips (1959). Belowground biomass was estimated by digging monolith of 25×25×25cm from each quadrat. The plant samples were brought to the laboratory and dried in oven at 80°C for 72 hours to find out their dry weight. Density, basal area and IVI was calculated by formulae given by Mishra (1969)

Estimation of carbon

Carbon in aboveground biomass of vegetation was estimated by following (Koach, 1989) and belowground biomass of vegetation, was estimated by following IPCC (2006).

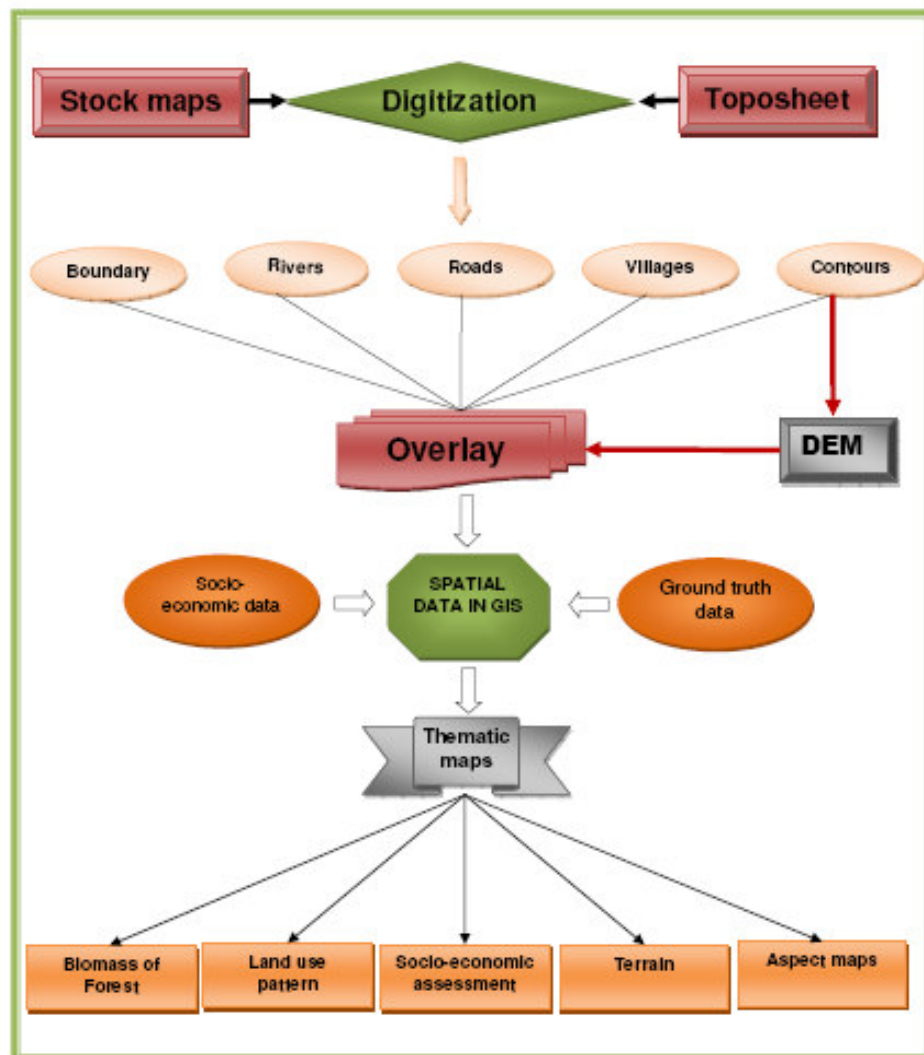


Fig. 2 Flow chart of GIS analysis

Soil analysis

Composite soil samples were collected from each forest/grassland by digging profile of 0-20cm and 20-40 cm in each forest. Samples were air dried in shade on ground, grinded in pestle and passed through 2 mm sieve and stored in cloth bags for further laboratory analysis. Bulk density were determined by weighing bottle method (Singh, 1980) whereas, organic carbon by Walkley and Black method (1934).

Carbon inventory

Carbon inventory was computed by multiplying the soil organic carbon with bulk density at each soil depth (Arias-Sanchez *et al.*, 2001).

Statistical analysis

The data was analysed by using analysis of variance - two way classification (Gupta, 1983).

Chapter-4

EXPERIMENTAL RESULTS

Socio-economic status

The total number of villages in “Ga3a” micro watershed was 37 (Fig. 3), in which 5 villages were located at higher elevation, 9 villages at middle elevation and 23 villages at lower elevation. Total population of the watershed was 4615 and average population density 219/km². The population density of different villages ranged from 8 - 4067 persons (Fig. 5). Nauni was the most populated village where as, Bhajo was least populated villages in the watershed having population of 401 and 4, respectively (Fig. 4). Nine villages in the micro-watershed had less population density as compared to the average population density of Himachal Pradesh (Fig. 6). House hold size on an average was 5 persons/household, while average land holding size per family was 10-20 bighas. The survey revealed on an average 85% literacy rate in the micro-watershed. Female per 1000 male in different villages ranged from 621 in Pandah to 1834 in Shewla brati (Fig. 7). Only six villages had less female ratio as compared to average female ratio for Himachal Pradesh (Fig. 8). Average sex ratio of the watershed was 961 female per 1000 male. The consumption of fuelwood and fodder was highest at higher elevation 9-11 and 14-16 (kg/household/day), respectively. While it was minimum at lower elevation 5-7 and 9-13 (kg/household/day) respectively. The common plant species used for fuel wood in this area were: *T. ciliata*, *C. australis*, *Acacia species*, *B. lycium*, *P. roxburghii* and *W. fruticosa* where as fodder species were: *G. optiva*, *B. variegata*, *C. australis* and *L. leucocephala*. The dependence of people on natural resources in this area revealed that fuelwood and fodder requirement was most important to them. The inhabitants also grow vegetable crops such as tomato, ginger and capsicum etc. along with pulses and maize. Maximum livestock was present at higher elevation (3-5/household) whereas

minimum livestock (2-3/household) were recorded at lower elevation (Table 1).

Delineation of land uses

The digitization of the contours at 20m using toposheet (53 F/1) procured from Forest Survey of India (Fig. 9) was done to prepare the Digital Elevation Model (DEM) of the micro-watershed (Fig 10). The DEM was re-classified into three elevation classes viz., 900-1300m, 1300-1600m and 1600m & above. It was found that 57.53% area of the micro-watershed was under 900-1300m elevation class, 26.40% under 1300 - 1600m and 16.06% under 1600m & above (Fig. 11). The DEM was further processed to calculate area under different aspects (Fig.12) and the percentage of area under different aspects were: 30.45 (SE), 5.18 (SW), 22.76 (NW) and 41.61(NE) The slope of the watershed (Fig. 13) revealed that at higher and middle elevation the slope averaged around 70%. Stockmap of the Solan Forest Division was used to identify land uses in the micro-watershed (Fig. 14)

Floristic composition

At lower elevation (900-1300m), in all, 18 grasses, 4 legumes, 4 sedges and 3 forbs were recorded. Whereas, in sites I, II, III and IV at this elevation total herbage species were: 14, 13, 20 and 19, respectively. At middle elevation (1300-1600m) a total of 17 grasses, 3 legumes, 2 sedges and 7 forbs were found while, in sites I, II and III at this elevation respective herbage species were: 15, 16 and 19 respectively. Likewise at higher elevation (1600m and above) a total of 17 grasses, 4 legumes, 4 sedge and 11 forbs were recorded and total species in sites I, II, III, IV and V at this elevation were: 13, 20, 14, 21 and 15 respectively.(Table 2)

Floristic composition of shrubs and herbs in all the elevations were same except for few species. The common shrubs and herbs in all the sites were: **shrubs:-** *Cotoneaster microphylla*, *Indigofera gerardiana*, *Osyris arborea*, *Woodfordia fruticosa*, *Berberis lycium*, *Hamiltonia*

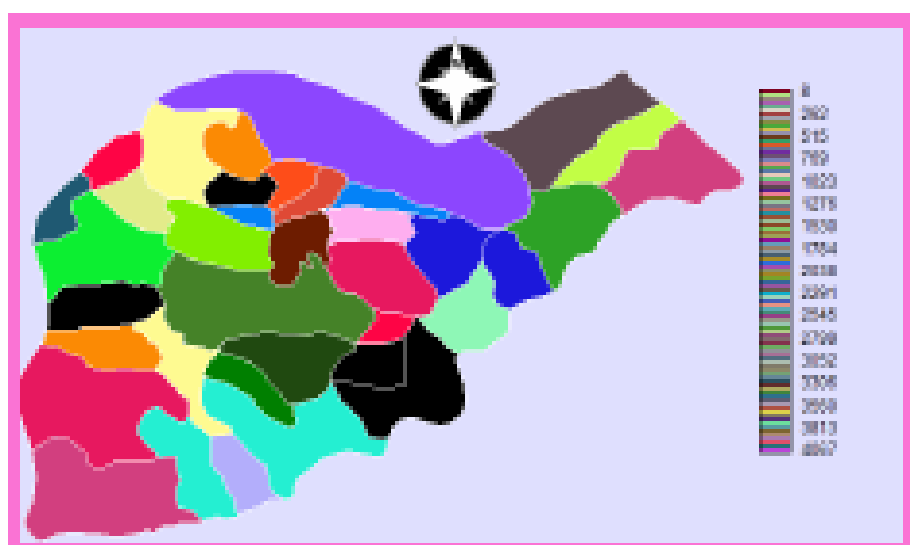


Fig.5. Population density of different villages of the micro-watershed

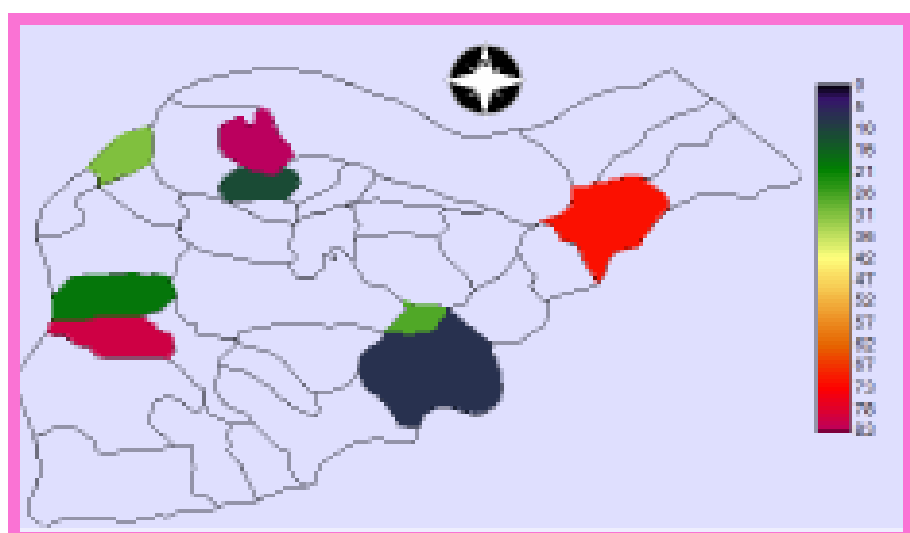


Fig.6. Villages in the micro-watershed having population density less than average population density for Himachal Pradesh

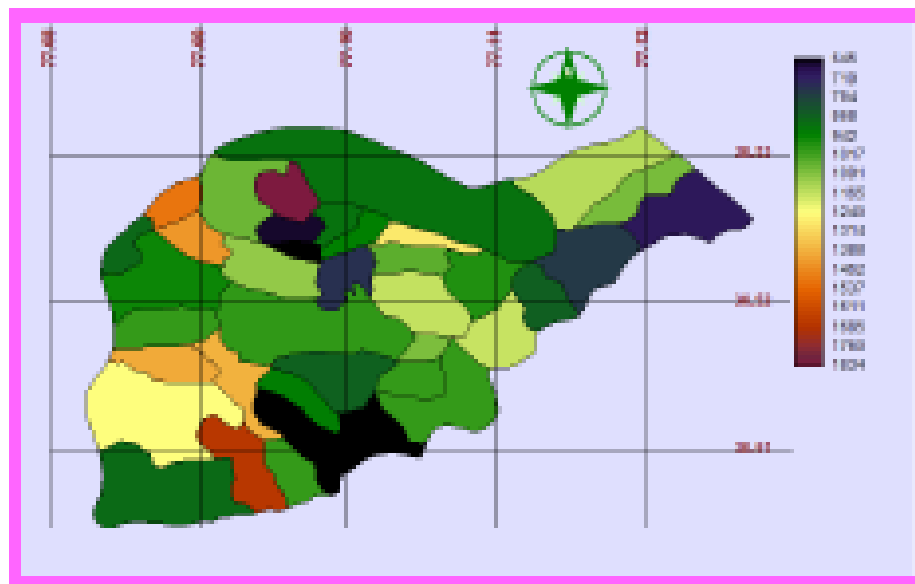


Fig. 7. Female per thousand male in different villages of the micro-watershed

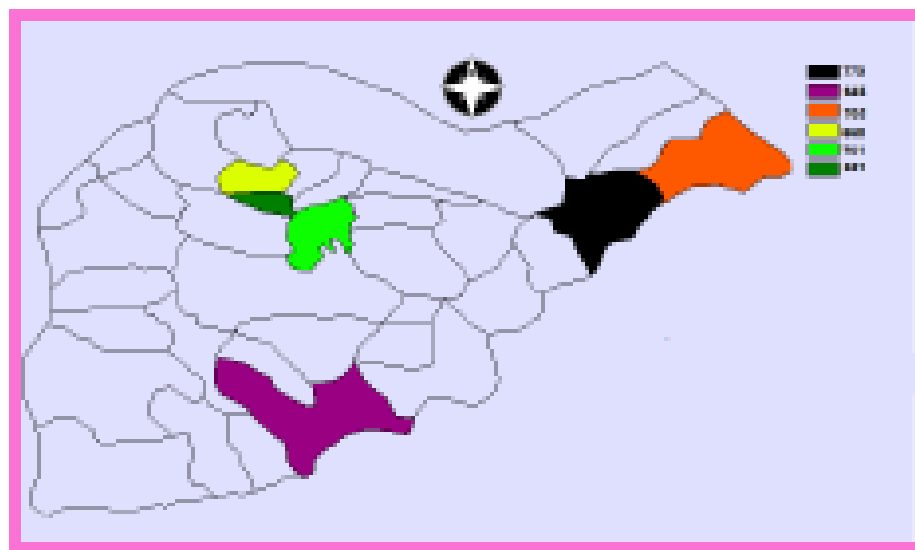


Fig. 8. Villages in the micro-watershed having less female sex ratio than average sex ratio for Himachal Pradesh



Fig.9. Digitization of contours at 20m interval

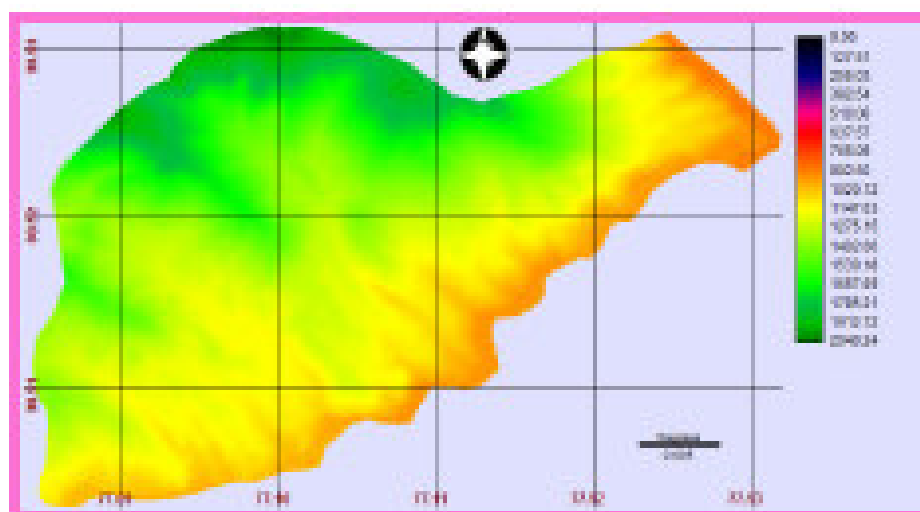


Fig.10. Digital Elevation Model (DEM) of the micro-watershed

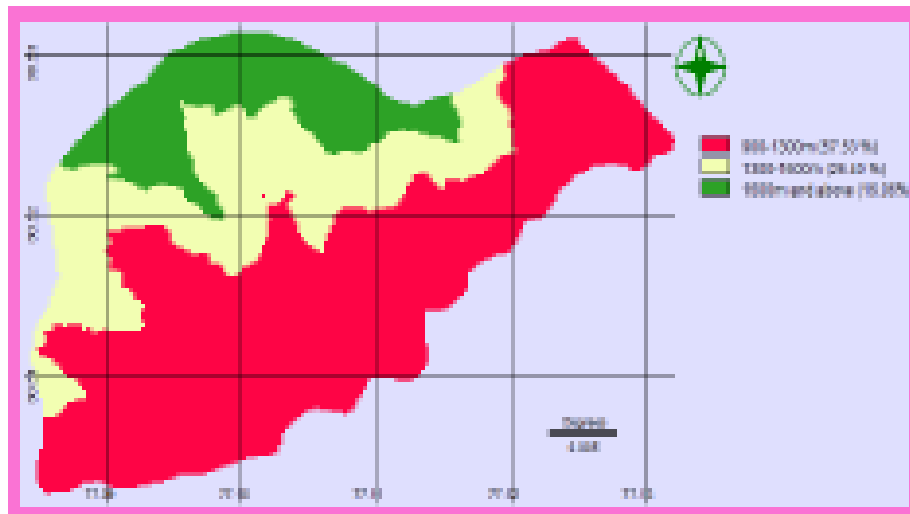


Fig.11. Area under three elevation classes in the micro-watershed

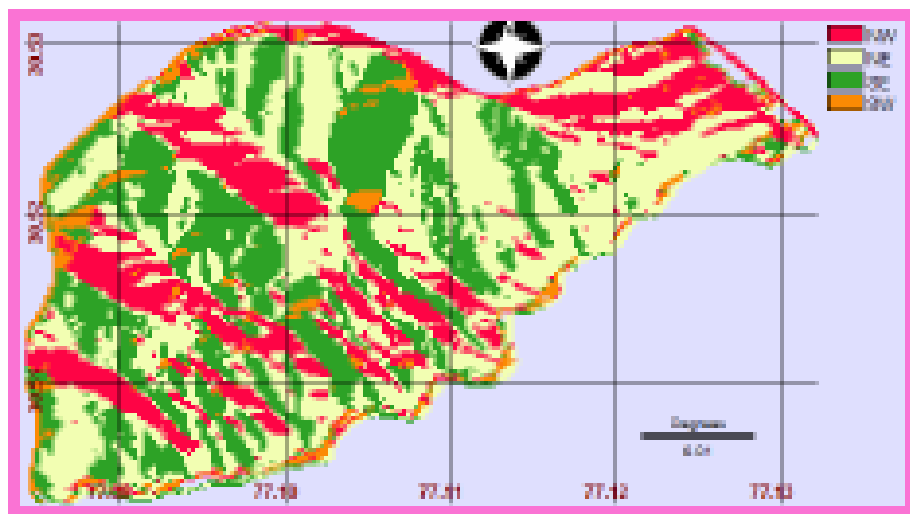


Fig. 12. Area under different aspects in the micro-watershed

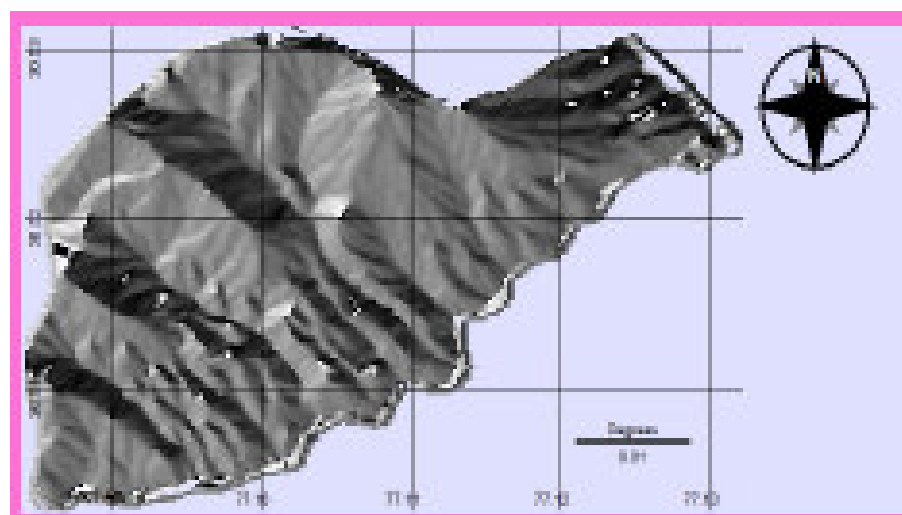


Fig.13. Overview of reman of the micro-watershed

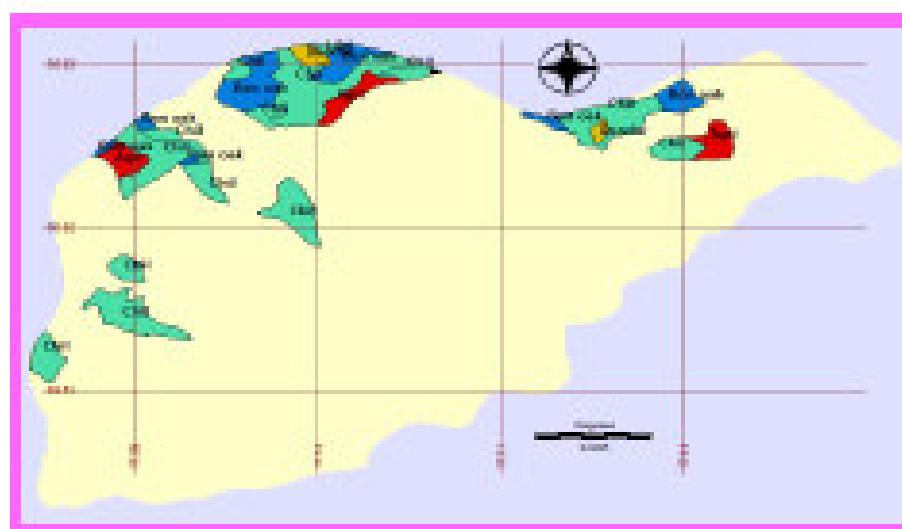


Fig. 14. Area under different land uses in the micro-watershed

Table 1: Fuelwood and Fodder requirements, Livestock number and Agriculture produce at different altitudes of ‘Ga3a’ micro-watershed

Elevation	Fuelwood		Fodder		Vegetables	Livestock
	Species	Quantity (kg/HH/Day)	Species	Quantity (kg/HH/Day)	Crops	Per house hold
900-1300m	<i>T. ciliata, C.australis, Acacia spp, B. lycium, P. roxburghii, W. fruticosa</i>	5-7	<i>G.optiva, B. veriegata, C. australis, L. leucocephala</i>	9-13	Tomato,Ginger,Capsicum, Maize,Chilli, pulses	2-3
1300-1600m	<i>T. ciliata, C.australis, Acacia spp, B. lycium, P. roxburghii, W. fruticosa</i>	6-9	<i>G.optiva, B. veriegata, C. australis,</i>	9-14	Tomato,Ginger,Capsicum, Maize,Chilli, colocasia,Peas, pulsesBeans	2-4
1600m and above	<i>T. ciliata, C.australis, A. spp, B. lycium, P. roxburghii, W. fruticosa Q. leucotrichophora</i>	9-11	<i>G.optiva, B. veriegata, C. australis, Q.leucotrichophora Q. leucotrichophora</i>	14-16	Tomato,Ginger,Capsicum, Maize,Chilli, Pulses, Patato, Beans, colocasia	3-5

Table 2: Consumption rates of fuelwood and fodder, vegetable cultivation and livestock population per household in “Ga3a” micro-watershed.

Elevation class		Lower elevation (900-1300m)				Middle elevation (1300-1600m)			Higher elevation (1600m and Above)				
Plants	Sites	I	II	III	IV	I	II	III	I	II	III	IV	V
		Grass- land	Chir pine	Mixed	Ban-oak	Grass- land	Chir pine	Mixed	Grass- land	Chir pine	Mixed	Ban-oak	Deodar
Trees		-	1	3	1	-	1	3	-	1	3	1	1
Shrubs		7	10	8	10	7	12	15	9	12	8	10	10
Herbs	Grasses	10	10	11	14	13	10	12	11	12	11	13	5
	Legumes	1	2	3	2	-	3	-	-	3	1	3	-
	Sedges	1	1	3	2	1	1	2	1	3	1	3	3
	Forbs	2	-	3	1	1	2	5	1	2	1	2	7
Total		21	24	31	30	22	29	37	22	33	25	32	26

suaveolens, *Pyrus pashia*, *Rosa moschata*, *Asparagus adscendens*, *Myrsine africana* and *Rubus ellipticus*; **grasses**:- *Apluda mutica*, *Arundinella nepalensis*, *Chrysopogon montanus*, *Chrysopogon fulvus*, *Dichanthium annulatum*, *Digitaria sanguinalis*, *Heteropogon contortus*, *Panicum maximum*, *Rottboellia exaltata*, *Themeda anathera*, *Urochloa panicoides* and *Setaria glauca*; **legumes**:- *Cassia mimosoides*, *Desmodium floribundum*, *Lespedeza gerardiana* and **sedges**:- *Carex wallichiana* and *Cyperus rotundus*.

In addition to these species, at lower elevation other species were **shrubs**:- *Carissa carandas*, *Caryopteris wallichiana*, *Lantana camara*, *Daphne cannabina*, *Lonicera quinquelocularis*, *Mimosa rubicaulis*, *Ziziphus Jujuba* and *Elaeagnus umbellata* **grasses**:- *Arundinella setosa*, *Chloris barbata*, *Cymbopogon martini*, *Eriophorum commosum*, *Eragrostis nigra* and *Paspalum notatum* The **legume** was: *Indigofera pulchella*. The **sedge** was: *Cyperus esculentus* and **forbs**:- *Micromeria biflora*, *Polystichum squarrosus*, *Thalictrum foliolosum* and *Thymus serphyllum*. Likewise, at middle elevation the other **shrubs** were *Coriaria nepalensis*, *Leptodermis lanceolata*, *Meriandra strobilifera*, *Justicia adhatoda*, *Rabolasia rugosus*, *Carissa carandas*, *Lantana camara*, *Caryopteris wallichiana*, *Leucas lanata* and *Mimosa rubicaulis*; **grasses** were: *Arundinella setosa*, *Chloris barbata*, *Cymbopogon martinii* and the **forbs** were: *Micromeria biflora*, *Microstegium vaganus*, *Viola pilosa*, *Tricholepis elongata*, *Thymus serphyllum*, *Barleria aristata* and *Cissampelos pareira*. At higher elevation the other **shrubs** were: *Zanthoxylum armatum*, *Sarcococca saligna*, *Wikstroemia canescens*, *Vitis himalayana*, *Cornus capitata*, *Daphne cannabina*, *Indigofera dosua*, *Jasminum officinale*, *Rabolasia rugosus*, *Indigofera gerardiana*, *Leptodermis lanceolata*, *Plectranthus rugosus*, *Prinsepia utilis*, *Hedera helix* and *Coriaria nepalensis*; **grasses** were: *Pennisetum orientale*, *Panicum orientale*, *Panicum colonum* and *Panicum sanguinale*; **legume** was: *Indigofera gerardiana*; **sedges**: *Carex wallichiana* and *Fimbristylis rigidula* and the **forbs** were: *Microstegium vaganus*, *Viola pilosa*, *Barleria aristata*,

Thalictrum foliolosum, *Pteris cretica*, *Polystichum discretum*, *Mulaxis acumenata*, *Arthyrium schimpeni* and *Thymus serpyllum*.

Phytosociology of herbage

At different elevation, in general, density (tillers/m²) and basal area (cm²/m²) of herbage increased gradually from July to September and declined in October. The combined contribution of forbs, legumes, and sedges to both the phytosociological attributes of herbage was less in comparison to the grasses in all the sampling months during the study period.

The phytosociological attributes of the herbage vegetation in different sites at lower elevation reveals that total density (tillers/m²) of herbage, in site I, during growing period ranged from 394.67 (July) to 1195.70 (September). Among individual species, *C. montanus* contributed highest density to the total density of vegetation and was followed by *P. maximum* and *H. contortus* in decreasing order. Their contributions ranged from 41.33-700.00, 84.70-224.70 and 57.33-644.00 tillers/m² respectively. Contribution of forbs, legumes and sedges to the total density of herbage vegetation was less than 12% in different months. Basal area (cm²/m²) of vegetation ranged from 11.68 to 98.23. *C. montanus* contribution was highest to the total basal area of vegetation in different sampling months and was followed by *H. contortus* and *P. maximum* in decreasing order. The dominant species in this site was *C. montanus* (IVI = 148.69 in August). Co-dominant species can be considered as: *H. contortus* and *P. maximum* with their respective IVI of 117.60 and 77.16 in the months of July and October, respectively (Table 3).

In site II, at lower elevation, total density (tillers/m²) fluctuated from 473.33 (July) to 639.32 (October). Highest contribution to total density of vegetation during different sampling months was recorded for *T. anathera* (220.00 to 411.33) followed by *A. nepalensis* (16.67 to 139.33) and *C. montanus* (57.33 to 84.00). The contribution of forbs, legumes and sedges to the total density of herbage

Table 3: Density, basal area and IVI of different herb species in grassland (Site I) at lower elevation (900-1300m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Arundinella nepalensis</i>	-	30.67	28.70	34.00	-	1.54	2.82	1.16	-	8.20	15.20	17.53
<i>Chrysopogon montanus</i>	41.33	700.00	195.00	611.30	1.26	43.81	23.86	41.15	37.17	148.69	64.17	134.79
<i>Cymbopogon martinii</i>	-	0.67	-	-	-	0.01	-	-	-	3.20	-	-
<i>Dichanthium annulatum</i>	14.00	24.67	8.67	-	0.66	2.99	0.56	-	17.18	9.92	7.56	-
<i>Eriophorum commosum</i>	-	11.36	-	-	-	1.34	-	-	-	5.95	-	-
<i>Heteropogon contortus</i>	172.67	57.33	644.00	194.70	5.81	2.45	35.25	9.94	117.60	18.58	90.12	43.11
<i>Panicum maximum</i>	113.33	162.00	84.70	224.70	2.62	7.84	5.64	12.23	75.22	42.54	21.17	77.16
<i>Rottboellia exaltata</i>	8.67	29.33	48.00	29.33	0.26	0.92	3.63	1.51	8.25	20.21	21.08	17.16
<i>Themeda anathera</i>	-	114.00	34.70	-	-	3.95	4.15	-	-	22.55	14.10	-
<i>Urochloa panicoides</i>	-	-	61.30	-	-	-	7.80	-	-	-	33.03	-
LEGUME												
<i>Cassia mimosoides</i>	-	3.33	-	10.00	-	0.03	-	0.42	-	10.10	-	5.60
SEDGES												
<i>Cyperus rotundus</i>	44.67	2.67	1.33	2.00	1.07	0.05	0.14	0.21	44.58	3.44	3.21	4.65
FORBS												
<i>Micromeria biflora</i>	-	0.67	-	-	-	0.08	-	-	-	6.63	-	-
<i>Polystichum squarrosum</i>	-	-	89.30	-	-	-	13.32	-	-	-	26.40	-
Total	394.67	1136.7	1195.7	1106.0	11.68	65.01	98.23	71.62	300	300	300	300

vegetation was less than 7% in different months. Total basal area of vegetation ranged from 9.59 to 44.60 cm²/m² and among individual species, *T. anathera* contributed highest basal area to the total basal area of vegetation in different sampling months. *A. nepalensis* and *C. montanus* followed by *T. anathera* in decreasing order and their contribution varied from 4.38 to 27.78, 2.18 to 5.90, 0.62 to 9.60 cm²/m², respectively. The dominant species in this site was *T. anathera* (IVI=168.94 in the month of August). Co-dominant species were: *A. nepalensis* and *C. montanus* which attained IVI of 71.66 and 60.42 in the months of September and July, respectively (Table 4).

A perusal of Table-5 indicates that, in site III, at lower elevation, total density of vegetation fluctuated from 577.98 (July) to 826.88 (September) tillers/m². *C. montanus* contributed the highest density (111.00 to 320.67 tillers/m²) to the total density of vegetation during different months and was followed by *H. contortus* (69.33 to 213.33 tillers/m²) and *T. anathera* (31.33 to 107.33 tillers/m²). The contribution of forbs, legumes and sedges was less than 15% to the total density of herbage in different months. Total basal area of vegetation in different months ranged from 16.93 to 55.45 cm²/m² in which *C. montanus* contributed highest (6.26 to 27.68 cm²/m²) among individual species followed by *H. contortus* (2.19 to 18.19 cm²/m²) and *T. anathera* (0.94 to 10.11 cm²/m²). Dominant species in this site was *C. montanus* (IVI = 113.93 in the month of August) and co-dominant species were: *H. contortus* and *A. nepalensis* with IVI of 63.26 and 50.14 in the months of September and October, respectively.

In site IV, at lower elevation, total density of vegetation ranged from 239.60 (July) to 660.99 (September) tillers/m². *T. anathera* contributed highest density to the total density of vegetation and was followed by *A. nepalensis* and *C. montanus* in decreasing order. Their contribution ranged from 58.00 to 218.67, 69.33 to 176.67 and 13.33 to 118.67 tillers/m², respectively. Legumes, sedges and forbs, combined contribution was less than 23% to the total density of herbage vegetation

Table 4: Density, basal area and IVI of different herb species in chir pine forest (Site II) at lower elevation (900-1300m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	9.33	-	21.33	-	0.08	-	1.75	-	6.15	-	24.51	-
<i>Arundinella nepalensis</i>	68.67	16.67	139.33	63.33	0.85	0.62	9.20	4.15	42.71	18.56	71.66	43.86
<i>Chloris barbata</i>	-	-	-	0.67	-	-	-	0.05	-	-	-	3.95
<i>Chrysopogon fulvus</i>	15.33	30.67	-	21.67	0.34	3.31	-	0.77	17.93	29.54	-	13.13
<i>Chrysopogon montanus</i>	84.00	70.00	57.33	79.33	2.18	4.86	5.65	5.90	60.42	41.40	39.92	35.26
<i>Dichanthium annulatum</i>	-	-	12.67	-	-	-	0.94	-	-	-	8.48	-
<i>Heteropogon contortus</i>	30.67	-	-	-	0.72	-	-	-	17.08	-	-	-
<i>Panicum maximum</i>	33.33	-	-	-	0.71	-	-	-	25.83	-	-	-
<i>Rottboellia exaltata</i>	12.00	-	-	-	0.33	-	-	-	9.30	-	-	-
<i>Themeda anathera</i>	220.00	411.33	400.00	399.33	4.38	21.82	26.80	27.78	120.58	168.94	140.92	157.42
LEGUMES												
<i>Cassia mimosoides</i>	-	24.67	3.33	19.33	-	0.46	0.12	1.17	-	19.47	9.19	25.32
<i>Lespedeza gerardiana</i>	-	2.67	-	2.00	-	0.05	-	0.13	-	5.00	-	8.31
SEDGES												
<i>Cyperus rotundus</i>	-	10.67	5.33	20.33	-	0.49	0.14	0.71	-	17.09	5.32	12.76
Total	473.33	566.68	639.32	605.99	9.59	31.61	44.60	40.66	300	300	300	300

Table 5: Density, basal area and IVI of different herb species in mixed forest (Site III) at lower elevation (900-1300m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	18.00	36.00	110.00	62.67	0.50	1.44	3.33	0.58	7.44	10.42	34.72	20.91
<i>Arundinella nepalensis</i>	77.30	63.33	8.00	106.67	2.39	5.22	4.00	10.40	32.15	30.17	18.30	50.14
<i>Chrysopogon fulvus</i>	33.33	20.00	41.33	-	0.86	0.94	1.21	-	17.33	7.29	12.28	-
<i>Chrysopogon montanus</i>	184.67	320.67	111.00	150.67	6.26	27.68	7.71	12.91	67.78	113.93	32.67	61.63
<i>Cymbopogon martinii</i>	19.00	42.00	-	-	1.17	3.37	-	-	12.60	14.93	-	-
<i>Dichanthium annulatum</i>	-	17.33	6.87	28.00	-	1.60	2.31	5.54	-	11.15	10.04	20.24
<i>Heteropogon contortus</i>	84.67	140.00	213.33	69.33	2.19	6.01	18.19	7.54	32.86	46.96	63.26	39.30
<i>Rottboellia exaltata</i>	14.00	39.33	65.30	18.00	0.97	2.18	5.23	1.20	11.18	18.99	21.33	9.70
<i>Setaria glauca</i>	-	-	45.33	24.00	-	-	1.38	0.58	-	-	13.08	7.35
<i>Themeda anathera</i>	76.67	31.33	98.67	107.33	0.94	1.51	5.04	10.11	25.05	12.87	28.87	52.84
<i>Urochloa panicoides</i>	24.67	-	3.30	77.33	0.68	-	0.15	5.29	12.21	-	3.11	27.37
LEGUMES												
<i>Desmodium floribundum</i>	9.00	2.00	7.34	-	0.19	0.01	1.33	-	60.79	3.07	8.33	-
<i>Indigofera pulchella</i>	-	5.34	4.66	-	-	0.04	0.06	-	-	12.25	3.11	-
<i>Lespedeza gerardiana</i>	-	-	11.33	7.33	-	-	0.94	0.10	-	-	8.11	7.35
SEDGES												
<i>Carex wallichiana</i>	-	-	15.33	1.33	-	-	0.33	0.02	-	-	7.49	3.17
<i>Cyperus esculentus</i>	-	9.33	-	-	-	0.81	-	-	-	8.54	-	-
<i>Cyperus rotundus</i>	36.67	6.00	6.93	-	0.78	1.52	1.50	-	20.61	9.43	8.45	-
FORBS												
<i>Thalictrum foliolosum</i>	-	-	1.33	-	-	-	0.05	-	-	-	2.68	-
<i>Micromeria biflora</i>	-	-	19.33	-	-	-	0.96	-	-	-	6.55	-
<i>Thymus serpyllum</i>	-	-	57.5	-	-	-	3.06	-	-	-	17.63	-
Total	577.98	732.66	826.88	652.66	16.93	52.33	55.45	54.27	300	300	300	300

during different months of the study period. Basal area of vegetation ranged from 9.31 to 24.96 cm²/m². Among different species *T. anathera* contributed highest basal area to the total basal area of vegetation followed by *A. nepalensis* and *C. montanus* in decreasing order and their contributions were: 2.28 to 10.46, 2.90 to 6.71, 2.40 to 5.22 cm²/ m², respectively. The dominant species in this site was *T. anathera* (IVI = 96.60 in the month of July). Co-dominant species were: *A. nepalensis* and *C. montanus* which attained IVI of 93.96 and 68.10, respectively in the month of August (Table 6).

Comparing four sites at lower elevation, it was evident from the Tables 3-6 that density and basal area of herbage was higher in site I and least in site II.

At middle elevation, in site I, numeric value of total density of vegetation ranged from 535.63 (August) to 1121.30 (September) tillers/m² (Table 7). Among individual species *C. montanus* contributed highest density to the total density of vegetation followed by *T. anathera* and *H. contortus* in decreasing order. They contributed 113.00 to 400.00, 34.30 to 215.33 and 6.00 to 156.67 tillers/m², respectively. The contribution of forbs, legumes and sedges to the total density of herbage vegetation was less than 2% during different months of the study period. A perusal of data further reveals that total basal area of vegetation ranged from 34.71 to 84.13cm²/m². Among individual species, *C. montanus* contributed highest basal area to the total basal area of vegetation and was followed by *T. anathera* and *H. contortus* in decreasing order. Their contributions ranged from 9.24 to 30.42, 1.16 to 17.96, and 0.69 to 10.42cm²/m², respectively. *C. montanus* (IVI = 88.65 in the month of August) was the dominant species. *T. anathera* and *P. maximum* were co-dominant species with IVI of 75.10 and 73.73 in the months of October and August, respectively.

In site II, at middle elevation, total density of vegetation fluctuated from 224.66 (July) to 886.00 (September) tillers/m². *T. anathera* had the

Table 6: Density, basal area and IVI of different herb species in ban-oak forest (Site IV) at lower elevation (900-1300m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	1.67	-	21.33	-	0.30	-	1.26	-	8.72	-	15.05
<i>Arundinella nepalensis</i>	69.33	176.67	154.67	76.67	2.90	6.71	4.07	3.74	85.18	93.96	57.26	52.02
<i>Arundinella setosa</i>	-	-	-	26.67	-	-	-	3.45	-	-	-	39.41
<i>Chrysopogon fulvus</i>	-	-	1.00	-	-	-	0.46	-	-	-	10.06	-
<i>Chrysopogon montanus</i>	13.33	118.67	108.00	51.33	2.40	5.22	4.18	3.69	52.15	68.10	47.09	47.67
<i>Dichanthium annulatum</i>	4.67	-	-	-	0.42	-	-	-	10.43	-	-	-
<i>Digitaria sanguinalis</i>	-	-	16.00	-	-	-	0.51	-	-	-	10.55	-
<i>Paspalum notatum</i>	-	4.00	11.33	-	-	0.21	0.49	-	-	4.52	6.66	-
<i>Eragrostis nigra</i>	-	4.67	1.33	-	-	0.08	0.51	-	-	6.65	3.17	-
<i>Heteropogon contortus</i>	26.00	30.00	67.33	26.67	0.78	1.18	2.00	2.30	31.79	17.86	27.04	27.82
<i>Panicum maximum</i>	-	28.00	-	-	-	0.70	-	-	-	14.85	-	-
<i>Rottboellia exaltata</i>	-	-	5.33	-	-	-	0.12	-	-	-	4.23	-
<i>Setaria glauca</i>	-	6.00	-	-	-	0.49	-	-	-	9.14	-	-
<i>Themeda anathera</i>	112.67	58.00	218.67	66.00	2.28	2.88	10.46	5.35	96.60	43.54	90.05	62.82
LEGUMES												
<i>Cassia mimosoides</i>	-	0.67	2.00	-	-	0.08	0.10	-	-	3.09	3.67	-
<i>Indigofera pulchella</i>	-	8.00	5.33	-	-	0.12	0.11	-	-	7.52	6.96	-
SEDGES												
<i>Cyperus esculentus</i>	-	19.33	59.34	74.67	-	0.37	1.64	1.66	-	11.25	21.5	44.97
<i>Cyperus rotundus</i>	13.60	-	5.33	2.00	0.53	-	0.23	0.05	23.85	-	4.71	10.24
FORBS												
<i>Micromeria biflora</i>	-	9.33	5.33	-	-	0.71	0.08	-	-	10.80	7.05	-
Total	239.6	465.01	660.99	345.34	9.31	19.05	24.96	21.50	300	300	300	300

Table 7: Density, basal area and IVI of different herb species in grassland (Site I) at middle elevation (1300-1600m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	-	5.33	28.67	-	-	0.01	1.63	-	-	5.69	17.50
<i>Arundinella nepalensis</i>	74.00	-	114.67	101.33	4.21	-	8.65	6.82	37.15	-	30.71	45.73
<i>Chrysopogon fulvus</i>	16.33	4.00	95.33	8.67	0.31	0.39	4.32	0.19	7.58	5.55	24.85	4.60
<i>Chrysopogon montanus</i>	113.00	171.33	400.00	199.33	9.24	13.44	30.42	9.97	70.40	88.65	88.19	74.00
<i>Cymbopogon martinii</i>	5.21	17.33	6.00	2.00	0.31	0.94	0.13	0.03	5.61	16.66	3.17	3.13
<i>Dichanthium annulatum</i>	31.00	-	39.33	-	2.31	-	2.44	-	19.74	-	14.16	-
<i>Heteropogon contortus</i>	123.00	156.67	114.00	6.00	8.12	9.24	10.42	0.69	60.97	67.83	35.4	8.54
<i>Panicum maximum</i>	63.00	85.33	30.00	106.67	3.72	7.02	1.66	2.61	29.77	73.73	7.13	34.63
<i>Pennisetum orientale</i>	-	27.33	-	-	-	2.42	-	-	-	20.95	-	-
<i>Rottboellia exaltata</i>	-	31.33	77.30	14.00	-	5.22	4.60	0.17	-	20.82	18.46	11.19
<i>Setaria glauca</i>	-	0.67	2.00	-	-	0.03	0.10	-	-	4.14	2.97	-
<i>Themeda anathera</i>	120.00	34.30	215.33	163.33	6.21	1.16	17.96	11.45	51.28	19.90	55.65	75.10
<i>Urochloa panicoides</i>	4.32	4.67	10.67	40.00	0.14	0.12	1.94	1.87	4.94	4.07	8.37	25.58
SEDGES												
<i>Cyperus rotundus</i>	7.00	0.67	11.33	-	0.13	0.06	1.48	-	9.38	3.04	5.25	-
FORBS												
<i>Cissampelos pareira</i>	0.67	2.00	-	-	0.01	0.15	-	-	3.19	4.66	-	-
Total	557.53	535.63	1121.3	670.00	34.71	40.19	84.13	35.43	300	300	300	300

maximum contribution ranged from 83.00 to 494.67 tillers/m² to the total density of vegetation and was followed by *A. nepalensis* and *C. martinii* with their contributions of 50.33 to 210.67 and 23.00 to 85.33 tillers/m² respectively. There was less than 10% contribution made by forbs, legumes and sedges to the total density of herbage vegetation in different months. Total basal area of vegetation ranged from 14.41 to 41.39 cm²/m². Among herb species *T. anathera* contributed highest basal area to the total basal area followed by *A. nepalensis* and *C. martinii* in decreasing order and their basal area contributions were: 7.94 to 23.82 and 3.01 to 9.99 and 0.86 to 5.70 cm²/m² respectively. *T. anathera* (IVI = 157.44, October) was the dominant species and *A. nepalensis* and *C. martinii* were co-dominant species with IVI values of 79.16 and 46.86 in the months of August and October, respectively (Table 8).

At middle elevation, in site III, total density of herbage varied from 400.66 (July) to 836.66 (September) tillers/m². In different months, highest density was observed for *C. montanus* (147.00 to 294.00) followed by *T. anathera* (61.00 to 166.67) and *A. mutica* (13.33 to 147.33). Only small contributions were made by forbs, legumes and sedges to the total density which was less than 8% in different months. Total basal area of vegetation ranged from 20.69 to 66.45 cm²/m² in which. *C. montanus* contributed the highest basal area followed by *T. anathera* and *A. nepalensis* in decreasing order and their contributions were: 8.21 to 25.15, 4.70 to 12.44 and 1.13 to 11.29 cm²/m², respectively. *C. montanus* was the dominant species with highest IVI (128.00) in the month of August (Table 9).

Comparing the three sites at middle elevation it was evident from the Tables 7-9 that density and basal area of herbage was higher in site I.

At higher elevation, in site I, total density of herbage ranged from 433.33 (July) to 1360.00 (September) tillers/m². Among grasses *H. contortus* contributed the highest density (51.00 to 359.33) followed by

Table 8: Density, basal area and IVI of different herb species in chir pine forest (Site II) at middle elevation (1300-1600m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	9.33	-	6.67	15.33	0.23	-	0.21	0.54	12.84	-	4.73	28.14
<i>Arundinella nepalensis</i>	50.33	154.00	210.67	124.67	3.01	7.54	9.99	4.87	61.33	79.16	65.97	60.58
<i>Arundinella setosa</i>	-	-	4.00	-	-	-	-	0.36	-	4.33	-	-
<i>Chloris barbata</i>	-	-	3.33	-	-	-	0.03	-	-	-	3.92	-
<i>Chrysopogon montanus</i>	16.00	-	49.33	-	1.01	-	2.29	-	24.87	-	18.28	-
<i>Cymbopogon martinii</i>	23.00	41.33	85.33	65.33	0.86	1.09	5.40	5.70	26.94	32.12	40.68	46.86
<i>Digitaria sanguinalis</i>	-	10.00	-	-	-	0.73	-	-	-	8.14	-	-
<i>Panicum maximum</i>	21.00	8.00	-	-	0.80	0.33	-	-	25.64	6.55	-	-
<i>Pennisetum orientale</i>	-	-	14.67	-	-	-	0.15	-	-	-	12.84	-
<i>Themeda anathera</i>	83.00	238.87	494.67	349.67	7.94	23.82	22.98	21.60	113.28	141.03	133.23	157.44
LEGUMES												
<i>Cassia mimosoides</i>	0.67	1.33	0.67	-	0.06	0.01	0.01	-	11.47	4.06	3.55	-
<i>Desmodium floribundum</i>	13.33	-	12.00	-	0.19	-	0.21	-	10.83	-	9.02	-
<i>Lespedza gerardiana</i>	8.00	12.00	-	-	0.31	0.35	-	-	12.8	15.59	-	-
SEDGES												
<i>Carex wallichiana</i>	-	-	1.33	6.67	-	-	0.01	0.23	-	-	3.65	6.98
FORBS												
<i>Cissampelos pareira</i>	-	3.33	-	-	-	0.07	-	-	-	9.02	-	-
<i>Micromeria biftora</i>	-	-	3.33	-	-	-	0.12	-	-	-	4.13	-
Total	224.66	468.86	886.00	561.67	14.41	33.94	41.39	33.30	300	300	300	300

Table 9: Density, basal area and IVI of different herb species in mixed forest (Site III) at middle elevation (1300-1600m)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	21.00	25.33	147.33	13.33	0.45	0.65	8.54	0.30	23.09	12.09	42.23	12.56
<i>Arundinella nepalensis</i>	73.00	80.67	18.67	207.33	2.01	2.22	1.13	11.29	37.37	35.71	9.80	62.13
<i>Chrysopogon fulvus</i>	-	-	22.00	-	-	-	0.85	-	-	-	6.76	-
<i>Chrysopogon montanus</i>	147.00	290.00	269.33	294.00	8.21	12.71	25.15	19.97	92.03	128.00	85.60	98.62
<i>Cymbopogon martinii</i>	-	-	60.00	-	-	-	1.70	-	-	-	21.49	-
<i>Dichanthium annulatum</i>	-	-	38.67	-	-	-	6.11	-	-	-	19.71	-
<i>Heteropogon contortus</i>	4.00	32.67	97.33	8.00	0.27	0.81	8.00	0.48	11.75	18.17	32.6	4.64
<i>Panicum maximum</i>	38.00	-	3.33	40.00	2.92	-	0.08	2.52	29.81	-	3.36	15.71
<i>Panicum orientale</i>	-	6.00	-	-	-	0.33	-	-	-	6.32	-	-
<i>Rottboellia exaltata</i>	-	18.67	6.67	-	-	0.35	0.63	-	-	13.58	7.62	-
<i>Themeda anathera</i>	61.00	76.00	143.33	166.67	4.70	5.72	12.44	9.47	53.76	53.14	50.1	56.04
<i>Urochloa panicoides</i>	25.00	-	14.67	58.67	1.63	-	1.30	2.75	20.34	-	9.58	23.9
SEDGES												
<i>Carex wallichiana</i>	7.00	3.33		8.00	0.12	0.14	-	0.69	5.35	5.04	-	7.15
<i>Cyperus rotundus</i>	3.33	-	13.33	5.33	0.10	-	0.49	0.28	7.55	-	8.20	3.90
FORBS												
<i>Barleria aristata</i>	-	1.33	-	6.67	-	0.03	-	0.07	-	2.88	-	6.03
<i>Thymus serpyllum</i>	3.67	2.00	2.00	6.67	0.06	0.05	0.03	0.23	4.23	3.01	2.95	6.77
<i>Microstegium vagans</i>	15.33	12.67	-	-	0.21	0.28	-	-	7.85	7.29	-	-
<i>Tricholepis elongata</i>	-	7.33	-	-		0.32	-	-	-	14.77	-	-
<i>Viola pilosa</i>	2.33	-	-	2.67	0.01	-	-	0.03	6.87	-	-	2.85
Total	400.66	556.00	836.66	817.34	20.69	23.61	66.45	48.08	300	300	300	300

P. maximum (70.33 to 292.67) and *T. anathera* (171.00 to 232.67) in decreasing order to the total density of vegetation. Forbs, legumes and sedges contributions was less than 9% to the total density of herbage vegetation, during different months of study period. Total basal area of vegetation ranged from 25.54 to 50.38 cm²/m² in which *T. anathera* contributed the highest (3.08 to 19.65) basal area to the total basal area of vegetation followed by *H. contortus* (1.53 to 12.57) and *C. montanus* (4.31 to 7.74) cm²/ m², respectively. *T. anathera* was the dominant species (IVI = 126.05 in the month of August). Co-dominant species were: *H. contortus* and *P. maximum* which attained IVI of 86.84 and 67.85 in the month of October, respectively (Table 10).

At higher elevation, in site II, the data in Table11 reveals that total density of herbage varied from 233.34 (August) to 595.31 (September) tillers/m². *T. anathera* contributed the highest density to the total density of vegetation in different months and was followed by *A. nepalensis* and *C. montanus* in decreasing order. Their contributions were: 108.67 to 237.33, 59.33 to 137.33 and 41.67 to 110.00 tillers/m², respectively. The contributions of forbs, legumes and sedges to the total density of herbage was less than 17% during different months of the study period. Further, the total basal area of herbage fluctuated between 20.62 to 36.08 cm²/m². *T. anathera* contributed highest basal area to the total basal area of herbage in different sampling months and was followed by *A. nepalensis* and *C. montanus* in decreasing order. Their contributions were: 8.24 to 13.57, 4.43 to 12.01 and 2.67 to 10.81 cm²/m², respectively. The dominant species with highest IVI was *T. anathera* (123.24 in the month of August). Co-dominant species were: *A. nepalensis* and *C. montanus* which attained IVI of 81.99 and 69.57 in the month of September, respectively.

In site III, at higher elevation, total density of herbage ranged from 336.66 (July) to 992.01 (September) tillers/m². Among grasses, *P. maximum* contributed the highest density (3.33 to 466.00) to the total

Table 10: Density, basal area and IVI of different herb species in grassland (Site I) at higher elevation (1600m and above)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	9.67	2.67	20.00	44.67	0.12	0.08	0.17	2.44	11.86	5.20	6.92	29.40
<i>Arundinella nepalensis</i>	30.00	50.00	142.00	70.00	3.20	4.35	4.39	5.26	28.61	30.71	26.89	38.13
<i>Chrysopogon fulvus</i>	-	-	117.33	20.00	-	-	5.92	1.12	-	-	33.23	16.16
<i>Chrysopogon montanus</i>	50.33	80.67	140.00	-	4.31	7.74	5.84	-	43.69	50.44	29.63	-
<i>Dichanthium annulatum</i>	3.67	-	6.67	-	0.45	-	0.69	-	5.54	-	4.34	-
<i>Heteropogon contortus</i>	51.00	23.33	359.33	137.33	2.20	1.53	10.72	12.57	35.58	23.02	63.18	86.84
<i>Panicum maximum</i>	70.33	93.33	292.67	131.33	4.00	6.43	7.41	6.84	47.09	59.24	49.08	67.85
<i>Pennisetum orientale</i>	6.67	-	7.33	8.00	0.10	-	0.12	0.69	4.86	-	5.89	12.64
<i>Rottboellia exaltata</i>	2.33	-	2.67	-	0.13	-	0.12	-	3.98	-	5.54	-
<i>Setaria glauca</i>	-	2.00	6.67	-	-	0.08	0.18	-	-	5.34	3.32	-
<i>Themeda anathera</i>	171.00	232.67	178.67	142.00	8.61	19.65	13.47	3.08	88.38	126.05	52.72	48.99
SEDGES												
<i>Cyperus rotundus</i>	31.00	-	74.67	-	2.40	-	1.30	-	25.71	-	15.81	-
FORBS												
<i>Thymus serpyllum</i>	7.33	-	12.00	-	0.02	-	0.05	-	4.70	-	3.46	-
Total	433.33	484.67	1360.0	553.33	25.54	39.86	50.38	32.00	300	300	300	300

Table 11: Density, basal area and IVI of different herb species in chir pine forest (Site II) at higher elevation (1600m and above)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	12.00	2.67	14.00	32.00	0.69	0.08	0.48	1.25	17.48	5.35	11.09	17.13
<i>Arundinella nepalensis</i>	61.33	59.33	137.33	79.33	5.31	4.72	12.01	4.43	63.18	66.35	81.99	41.25
<i>Chrysopogon fulvus</i>	-	46.67	-	-	-	4.71	-	-	-	65.01	-	-
<i>Chrysopogon montanus</i>	41.67	-	110.00	59.33	2.67	-	10.81	2.84	43.75	-	69.57	27.27
<i>Dichanthium annulatum</i>	12.67	-	9.33	15.33	0.94	-	0.31	0.98	15.48	-	6.09	10.99
<i>Heteropogon contortus</i>	16.33	4.00	11.33	24.67	0.93	0.27	0.69	0.96	13.24	6.76	11.12	12.35
<i>Panicum colonum</i>	-	1.33	5.33	-	-	0.12	0.09	-	-	4.97	4.68	-
<i>Panicum maximum</i>	-	-	40.00	-	-	-	1.54	-	-	-	15.69	-
<i>Panicum orientale</i>	-	-	-	18.67	-	-	-	0.62	-	-	-	12.99
<i>Panicum sanguinale</i>	-	-	7.33	-	-	-	0.26	-	-	-	5.55	-
<i>Themeda anathera</i>	117.33	108.67	237.33	206.67	9.10	11.89	8.24	13.57	103.89	123.24	71.53	105.9
<i>Urochloa panicoides</i>	-	-	-	15.33	-	-	-	0.59	-	-	-	12.11
LEGUMES												
<i>Cassia mimosoides</i>	0.67	4.67	-	2.67	0.06	0.54	-	0.04	10.6	12.39	5.54	12.39
<i>Indigofera pulchella</i>	8.67	-	-	8.67	0.15	-	-	0.20	6.88	-	-	12.17
<i>Lespedeza gerardiana</i>	4.33	2.00	5.33	-	0.10	0.01	0.23	-	5.17	4.79	5.08	-
SEDGES												
<i>Carex wallichiana</i>	4.33	-	8.00	1.30	0.25	-	1.20	0.21	5.90	-	8.29	3.41
<i>Cyperus esculentus</i>	-	4.00	8.00	36.00	-	0.33	0.21	0.80	-	11.14	-	13.55
<i>Cyperus rotundus</i>	17.00	-	-	26.67	0.42	-	-	0.31	14.43	-	-	12.80
FORBS												
<i>Barleria aristata</i>	-	-	2.00	-	-	-	0.01	-	-	-	3.78	-
<i>Thymus serphyllum</i>	-	-	-	16.00	-	-	-	0.21	-	-	-	5.69
Total	295.66	233.34	595.31	542.64	20.62	22.67	36.08	27.01	300	300	300	300

density of herbage and was followed by *C. montanus* (130.00 to 228.00 tillers/m²) and *T. anathera* (66.67 to 198.67 tillers/m²). The contribution of forbs, legumes and sedges to the total density of herbage vegetation was less than 7% during different months of the study period. Total basal area of herbage in this site ranged from 16.78 to 41.03 cm²/m². *T. anathera* contributed highest basal area (3.37 to 17.62 cm²/ m²) to the total basal area of herbage in different months. It was followed by *P. maximum* and *C. montanus* in decreasing order for their contributions to the total basal area of herbage with 0.21 to 15.65 and 7.31 to 14.88 cm²/ m² basal area, respectively. The dominant species with highest IVI was *C. montanus* (113.57 in the month of July). *P. maximum* and *T. anathera* were the co-dominant species with IVI values of 107.70 and 104.76 in the months of September and August, respectively (Table 12).

In site IV, at higher elevation, total density of herbage varied from 283.68 (July) to 562.67 (September) tillers/m². Highest contribution to total density was recorded from *T. anathera* (105.00 to 216.00 tillers/m²) followed by *A. mutica* (21.33 to 212.67 tillers/m²) and *A. nepalensis* (31.00 to 119.33 tillers/m²), respectively. The contribution of forbs, legumes and sedges to the total density of herbage vegetation was less than 6% in different months. Total basal area of herbage varied from 18.33 to 35.62 cm²/m² in which, *T. anathera* contributed highest basal area (6.31 to 15.61) to the total basal area of herbage. Considerable contributions were also made by *A. mutica* (0.98 to 10.02 cm²/m²) and *A. nepalensis* (3.21 to 6.35 cm²/ m²). The dominant species in this site was *T. anathera* (IVI = 135.17 in the month of August) (Table 13).

At higher elevation, in site V, total density of vegetation varied from 246.34 (July) to 301.68 (September) tillers/m². *C. esculentus* (141.00 to 193.01) contributed highest density to the total density of herbage and were followed by *F. rigidula* (4.67 to 38.00) and *A. schimpeni* (11.30 to 28.00) tillers/m². The contribution of grasses to the total density of herbage vegetation was less than 15% during different months of the

Table 12: Density, basal area and IVI of different herb species in mixed forest (Site III) at higher elevation (1600m and above)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	33.00	-	-	19.33	1.11	-	-	1.42	21.47	-	-	16.44
<i>Arundinella nepalensis</i>	5.33	6.67	16.00	26.00	0.42	0.69	0.72	1.24	14.78	10.65	9.78	20.73
<i>Chrysopogon fulvus</i>	-	-	-	4.00	-	-	-	0.14	-	-	-	4.77
<i>Chrysopogon montanus</i>	130.00	214.00	228.00	191.33	7.31	14.88	9.68	10.4	113.57	97.09	64.54	95.75
<i>Dichanthium annulatum</i>	-	17.33	-	5.33	-	1.35	-	0.33	-	22.01	-	5.79
<i>Heteropogon contortus</i>	-	42.67	122.67	22.00	-	3.01	6.13	1.19	-	34.9	47.63	23.22
<i>Panicum maximum</i>	50.00	3.33	466.00	153.33	1.00	0.21	15.65	5.86	31.29	4.89	107.7	70.72
<i>Pennisetum orientale</i>	-	10.67	1.33	8.00	-	1.33	0.48	0.14	-	9.03	4.43	5.56
<i>Rottboellia exaltata</i>	17.00	22.00	-	-	1.32	1.94	-	-	17.97	16.67	-	-
<i>Themeda anathera</i>	81.00	198.67	66.67	70.00	5.21	17.62	3.37	4.61	70.84	104.76	25.16	45.89
<i>Urochloa panicoides</i>	-	-	22.00	-	-	-	0.27	-	-	-	9.16	-
LEGUMES												
<i>Indigofera pulchella</i>	6.33	-	8.67	-	0.10	-	0.15	-	7.57	-	7.49	-
SEDGES												
<i>Cyperus rotundus</i>	14.00	-	58.67	12.00	0.31	-	0.87	0.42	22.51	-	20.69	11.13
FORBS												
<i>Berleria aristata</i>	-	-	2.00	-	-	-	0.08	-	-	-	3.42	-
Total	336.66	515.34	992.01	511.32	16.78	41.03	37.40	25.75	300	300	300	300

Table 13: Density, basal area and IVI of different herb species in ban-oak forest (Site IV) at higher elevation (1600 m and above)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
GRASSES												
<i>Apluda mutica</i>	21.33	26.67	45.33	212.67	1.21	0.98	2.37	10.02	22.38	23.14	33.47	87.97
<i>Arundinella nepalensis</i>	31.00	-	119.33	36.67	3.21	-	6.35	4.35	41.63	-	44.22	29.42
<i>Chrysopogon fulvus</i>	40.00	-	58.00	17.33	1.90	-	2.38	1.00	33.73	-	31.25	12.38
<i>Chrysopogon montanus</i>	19.67	22.67	10.67	110.00	1.76	2.14	0.85	5.40	29.76	28.10	8.86	54.43
<i>Dichanthium annulatum</i>	9.33	-	26.67	20.00	0.97	-	3.40	1.59	11.23	-	19.14	20.75
<i>Digitaria sanguinalis</i>	3.67	-	-	2.00	0.05	-	-	0.09	7.02	-	-	3.59
<i>Heteropogon contortus</i>	19.67	20.67	44.00	10.00	1.51	1.61	2.33	0.49	23.44	19.52	19.10	9.44
<i>Panicum maximum</i>	-	41.33	-	-	-	1.75	-	-	-	36.74	-	-
<i>Panicum orientale</i>	-	-	-	4.00	-	-	-	0.51	-	-	-	5.25
<i>Panicum sanguinale</i>	3.67	-	-	4.00	0.11	-	-	0.39	4.54	-	-	4.87
<i>Setaria glauca</i>	-	-	-	2.00	-	-	-	0.08	-	-	-	3.55
<i>Themeda anathera</i>	105.00	176.67	216.00	110.00	6.31	9.85	15.61	8.09	87.00	135.17	88.45	62.82
<i>Urochloa panicoides</i>	13.67	38.67	19.33	-	0.40	2.00	0.58	-	12.46	42.09	14.39	-
LEGUMES												
<i>Cassia mimosoides</i>	-	6.67	1.33	-	-	0.33	0.01	-	-	8.59	4.76	-
<i>Desmodium floribundum</i>	2.67	3.33	1.33	-	0.10	0.15	0.12	-	4.13	6.65	4.87	-
<i>Indigofera pulchella</i>	1.33	-	2.67	-	0.04	-	0.05	-	3.33	-	5.12	-
SEDGES												
<i>Carex wallichiana</i>	-	-	6.00	-	-	-	0.02	-	-	-	5.6	-
<i>Cyperus esculentus</i>	4.67	-	2.67	-	0.03	-	0.01	-	7.26	-	4.98	-
<i>Cyperus rotundus</i>	5.67	-	6.00	6.00	0.22	-	0.21	0.48	5.84	-	6.17	5.53
FORBS												
<i>Microstegium vaganus</i>	2.33	-	2.67	-	0.51	-	1.32	-	6.25	-	5.01	-
<i>Thymus serpyllum</i>	-	-	0.67	-	-	-	0.01	-	-	-	4.61	-
Total	283.68	336.68	562.67	534.67	18.33	18.81	35.62	32.49	300	300	300	300

study period. Total basal area of herbage ranged from 11.77 to 25.98 cm^2/m^2 in which, *C. esculentus* contributed highest cm^2/m^2 . The dominant species with highest IVI was *C. esculentus* (148.30 in the month of October) (Table 14).

Comparing five sites at higher elevation it was evident from the Tables (10-14) that density and basal area was higher at site I, while it was least in site V.

Statistical analysis of data (Tables 15-16) reveals that density and basal area of herbage was significantly low in chir pine and mixed forests as compared to grassland. The effect of elevation on density of herbage in grasslands revealed that it was maximum at higher elevation and at par at low and middle elevations. Effect of elevation on basal area of herbage in grassland revealed that, it decreased significantly with increase in elevation. In chir pine and mixed forests the density of herbage decreased significantly at higher elevation as compared to lower elevation.

Biomass of herbage

The biomass (aboveground and belowground) of herbage in different sites at three elevations revealed that, in general, it increased gradually from July to September and thereafter decreased. Total contribution of forbs, legumes, and sedges to the biomass of herbage was less in comparison to grasses. Higher biomass of herbage was recorded in grasslands in comparison to other sites.

In site I, at lower elevation, aboveground biomass, during sampling months varied from 0.988 to 4.268 t/ha. *C. montanus*, *H. contortus* and *P. maximum* contributions to the total aboveground biomass of herbage were higher than other species. Their respective aboveground biomass ranged from: 0.411-2.561, 0.135-1.310 and 0.291-0.921 t/ha. Total belowground biomass of herbage fluctuated between 1.275-5.451 (t/ha). The contributions of *C. montanus*, *H. contortus* and *P. maximum* to the total belowground biomass of herbage were higher than

Table 14: Density, basal area and IVI of different herb species in deodar forest (Site V) at higher elevation (1600 m and above)

Plant categories/species	Density (tillers/m ²)				Basal area (cm ² /m ²)				IVI			
	months				months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	8.67	-	6.00	-	0.37	-	0.17	-	15.84		4.88
<i>Avena sterilis</i>	-	-	4.00	11.31	-	-	0.08	0.33	-	-	4.67	7.15
<i>Digitaria sanguiolis</i>	11.00	15.30	18.70	23.33	0.20	0.43	0.89	0.76	15.08	21.89	25.41	20.97
<i>Panicum colonum</i>	2.00	-	2.00	2.67	0.03	-	0.03	0.04	3.96	-	3.83	5.57
<i>Urochloa panicoides</i>	4.67	5.33	1.33	-	0.11	0.12	0.09	-	8.74	6.06	3.82	-
SEDGES												
<i>Carex longioris</i>	15.67	-	14.70	17.33	1.57	-	2.21	1.41	33.07	-	29.16	32.78
<i>Cyperus esculentus</i>	141.00	161.33	193.01	155.67	8.70	7.22	16.11	9.20	139.63	141.00	138.91	148.30
<i>Fimbristylis rigidula</i>	7.67	38.00	6.67	4.67	0.31	1.59	0.19	0.85	14.33	57.23	6.01	24.83
FORBS												
<i>Arthyrium schimpeni</i>	23.33	-	11.30	28.00	0.91	-	2.74	0.66	25.30	-	26.20	17.01
<i>Microstegium vaganus</i>	2.33	3.33	-	14.27	0.03	0.06	-	0.09	7.20	7.99	-	6.28
<i>Mulaxis acumenata</i>	5.67	-	11.30	6.00	0.10	-	0.76	0.13	9.07	-	12.92	6.82
<i>Polystichum discretum</i>	17.67	19.33	10.00	-	1.31	1.64	0.81	-	22.83	36.80	18.99	-
<i>Pteris cretica</i>	9.33	10.67	24.00	15.33	0.31	0.34	1.78	0.33	15.21	13.15	21.14	17.47
<i>Thalictrum foliolosum</i>	6.00	-	4.67	9.33	0.03	-	0.29	0.03	5.58	-	8.94	5.45
<i>Viola pilosa</i>	-	-	-	0.67	-	-	-	0.01	-	-	-	2.49
Total	246.34	261.96	301.68	294.58	13.61	11.77	25.98	13.16	300	300	300	300

Table 15. Interaction between density of herbs in different grassland /forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	1125.0	606.0	826.9	852.7
Middle (1300-1600)	1121.0	886.0	836.7	948.0
Higher (1600 and above)	1360.0	642.6	992.0	998.2
Mean	1202.0	711.5	885.2	

		SE $\pm$	CD _{0.05}
T	=	49.69	105.34
F	=	49.69	105.34
TxF	=	86.07	182.42

Table 16. Interaction between basal area of herbs in different grassland /forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	98.23	44.60	55.45	66.09
Middle (1300-1600)	84.13	41.39	66.45	63.09
Higher (1600 and above)	50.38	36.08	41.03	42.50
Mean	77.58	40.69	54.31	

		SE $\pm$	CD _{0.05}
T	=	3.14	6.66
F	=	3.14	6.66
TxF	=	5.44	11.53

other species. Their contributions were: 0.540-3.303, 0.142-1.981 and 0.313-0.941 t/ha, respectively. The contribution of forbs, legumes, and sedges to the total above and belowground biomass was less than 16 and 21%, respectively (Table 17).

In site II, at lower elevation, aboveground biomass ranged from 2.094-3.647 t/ha. The contribution of *T. anathera* (1.231-1.790 t/ha), *A. nepalensis* (0.081-0.721 t/ha) and *C. fulvus* (0.232-0.629 t/ha) were higher than other species. Belowground biomass of herbage varied between 2.255-3.527 t/ha and the contributions of *T. anathera*, *C. fulvus* and *A. nepalensis* to the total belowground biomass of herbage were

Table 17: Monthly biomass (t/ha) of different herb species in grassland (Site I) at lower elevation (900-1300m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Arundinella nepalensis</i>	-	0.153	0.234	0.344	-	0.164	0.163	0.074
<i>Chrysopogon montanus</i>	0.411	2.561	0.691	1.981	0.540	3.303	1.204	2.387
<i>Cymbopogon martinii</i>	-	0.014	-	-	-	0.015	-	-
<i>Dichanthium annulatum</i>	0.042	0.241	0.096	-	0.104	0.281	0.110	-
<i>Eriophorum commosum</i>	-	0.054	-	-	-	0.021	-	-
<i>Heteropogon contortus</i>	0.135	0.161	1.310	0.493	0.142	0.151	1.981	0.782
<i>Panicum maximum</i>	0.320	0.425	0.291	0.921	0.325	0.313	0.327	0.941
<i>Rottboellia exaltata</i>	0.053	0.104	0.195	0.104	0.137	0.084	0.012	0.061
<i>Themeda anathera</i>	-	0.281	0.177	-	-	0.571	0.095	-
<i>Urochloa panicoides</i>	-	-	0.631	-	-	-	0.454	-
LEGUME								
<i>Cassia mimosoides</i>	-	0.012	-	0.071	-	0.064	-	0.164
SEDGES								
<i>Cyperus rotundus</i>	0.027	0.014	0.016	0.014	0.027	0.022	0.023	0.012
FORBS								
<i>Micromeria biflora</i>	-	0.043	-	-	-	0.033	-	-
<i>Polystichum squarrosum</i>	-	-	0.627	-	-	-	1.082	-
Total	0.988	4.063	4.268	3.928	1.275	5.022	5.451	4.421

higher than other species. Their contributions ranged from 1.122-1.482, 0.280-0.704 and 0.091-0.631 (t/ha), respectively. The contribution of forbs, legumes, and sedges to the total above and belowground biomass was < 28% (Table 18).

At lower elevation, in site III, aboveground biomass of herbs in different months varied from 1.451-4.728 t/ha with maximum in *C. montanus* (0.221-0.880 t/ha) followed by *H. contortus* (0.280-0.731t/ha). Likewise belowground biomass fluctuated between 1.903-4.107 t/ha. The data reveals that the contribution of *C. montanus* and *A. nepalensis* to the total belowground biomass of herbage was higher than other species. Their contribution was 1.281-0.152 and 0.271-0.664 (t/ha), respectively. Total above and below ground biomass contributed by forbs, legumes, and sedges was less than 32 and 38%, respectively (Table 19).

In site IV at lower elevation, aboveground biomass of herbs ranged from 0.396-1.581 t/ha. Major contributors were *A. nepalensis* (0.157-0.0.467 t/ha), *C. montanus* (0.103-0.338 t/ha) and *T. anathera* (0.023-0.266 t/ha), while total belowground biomass fluctuated between 0.439-1.701 t/ha. *A. nepalensis*, *C. montanus* and *T. anathera* were the key contributors to belowground biomass with their contributions as 0.133-0.392, 0.163-0.315 and 0.046-0.278 (t/ha) respectively. The contribution of forbs, legumes, and sedges to the total above and belowground biomass was less than 29 and 37% respectively (Table 20).

Comparing four sites at lower elevation (Table17-20) it was evident that aboveground biomass of herbage was higher in site I while belowground biomass was maximum in site III.

At middle elevation, a perusal of data for site I, revealed that the aboveground biomass varied from 1.585-5.581t/ha. Maximum contribution to the total biomass was by *C. montanus*, *T. anathera* and *A. nepalensis* their respective aboveground biomass range was 0.558-2.097, 0.236-1.120 and 0.437-0.816 (t/ha). Likewise belowground biomass (t/ha)

Table 18: Monthly biomass (t/ha) of different herb species in chir pine forest (Site II) at lower elevation (900-1300m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.032	-	0.230	-	0.032	-	0.211	-
<i>Arundinella nepalensis</i>	0.081	0.131	0.721	0.470	0.091	0.631	0.530	0.341
<i>Chloris barbata</i>	-	-	-	0.013	-	-	-	0.051
<i>Chrysopogon fulvus</i>	0.232	0.620	-	0.311	0.280	0.704	-	0.290
<i>Chrysopogon montanus</i>	0.130	0.252	0.439	0.304	0.141	0.161	0.690	0.391
<i>Dichanthium annulatum</i>	-	-	0.123	-	-	-	0.141	-
<i>Heteropogon contortus</i>	0.081	-	-	-	0.083	-	-	-
<i>Panicum maximum</i>	0.083	-	-	-	0.137	-	-	-
<i>Rottboellia exaltata</i>	0.135	-	-	-	0.141	-	-	-
<i>Themeda anathera</i>	1.320	1.231	1.790	1.361	1.350	1.122	1.482	1.410
LEGUMES								
<i>Cassia mimosoides</i>	-	0.233	0.312	0.570	-	0.040	0.371	0.291
<i>Lespedeza gerardiana</i>	-	0.023	-	0.262	-	0.032	-	0.371
SEDGES								
<i>Cyperus rotundus</i>	-	0.054	0.032	0.083	-	0.051	0.102	0.152
Total	2.094	2.544	3.647	3.374	2.255	2.741	3.527	3.297

Table 19: Monthly biomass (t/ha) of different herb species in mixed forest (Site III) at lower elevation (900-1300m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.231	0.580	0.415	0.182	0.372	0.620	0.481	0.153
<i>Arundinella nepalensis</i>	0.240	0.303	0.340	0.673	0.271	0.361	0.387	0.664
<i>Chrysopogon fulvus</i>	0.052	0.071	0.113	-	0.065	0.054	0.043	-
<i>Chrysopogon montanus</i>	0.221	0.880	0.391	0.810	0.155	0.780	0.152	1.281
<i>Cymbopogon martinii</i>	0.102	0.212	-	-	0.151	0.263	-	-
<i>Dichanthium annulatum</i>	-	0.091	0.112	0.411	-	0.052	0.096	0.393
<i>Heteropogon contortus</i>	0.280	0.410	0.731	0.350	0.321	0.212	0.421	0.176
<i>Rottboellia exaltata</i>	0.021	0.114	0.590	0.074	0.066	0.193	0.640	0.092
<i>Setaria glauca</i>	-	-	0.018	0.017	-	-	0.026	0.022
<i>Themeda anathera</i>	0.022	0.107	0.502	0.350	0.105	0.224	0.441	0.210
<i>Urochloa panicoides</i>	0.121	-	0.013	0.391	0.181	-	0.043	0.490
LEGUMES								
<i>Desmodium floribundum</i>	0.135	0.017	0.880	-	0.183	0.027	0.940	-
<i>Indigofera pulchella</i>	-	0.014	0.014	-	-	0.062	0.037	-
<i>Lespedeza gerardiana</i>	-	-	0.035	0.012	-	-	0.026	0.033
SEDGES								
<i>Carex wallichiana</i>	-	-	0.062	0.011	-	-	0.042	0.014
<i>Cyperus esculentus</i>	-	0.071	-	-	-	0.071	-	-
<i>Cyperus rotundus</i>	0.026	0.092	0.323	-	0.033	0.124	0.374	-
FORBS								
<i>Micromeria biflora</i>	-	-	0.083	-	-	-	0.132	-
<i>Thalictrum foliolosum</i>	-	-	0.014	-	-	-	0.085	-
<i>Thymus serpyllum</i>	-	-	0.092	-	-	-	0.041	-
Total	1.451	2.962	4.728	3.281	1.903	3.043	4.407	3.528

Table 20: Monthly biomass (t/ha) of different herb species in ban-oak forest (Site IV) at lower elevation (900-1300m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	0.112	-	0.031	-	0.253	-	0.057
<i>Arundinella nepalensis</i>	0.157	0.174	0.467	0.213	0.133	0.147	0.392	0.211
<i>Arundinella setosa</i>	-	-	-	0.242	-	-	-	0.286
<i>Chrysopogon fulvus</i>	-	-	0.020	-	-	-	0.032	-
<i>Chrysopogon montanus</i>	0.103	0.218	0.164	0.338	0.163	0.186	0.251	0.315
<i>Dichanthium annulatum</i>	0.012	-	-	-	0.022	-	-	-
<i>Digitaria sanguinalis</i>	-	-	0.075	-	-	-	0.044	-
<i>Paspalum notatum</i>	-	0.040	0.029	-	-	0.066	0.031	-
<i>Eragrostis nigra</i>	-	0.338	0.024	-	-	0.392	0.030	-
<i>Heteropogon contortus</i>	0.072	0.159	0.108	0.085	0.043	0.117	0.082	0.067
<i>Panicum maximum</i>	-	0.042	-	-	-	0.078	-	-
<i>Rottboellia exaltata</i>	-	-	0.018	-	-	-	0.036	-
<i>Setaria glauca</i>	-	0.058	-	-	-	0.017	-	-
<i>Themeda anathera</i>	0.023	0.264	0.219	0.266	0.046	0.278	0.181	0.266
LEGUMES								
<i>Cassia mimosoides</i>	-	0.027	0.048	-	-	0.053	0.079	-
<i>Indigofera pulchella</i>	-	0.040	0.050	-	-	0.060	0.080	-
SEDGES								
<i>Cyperus esculentus</i>	-	0.029	0.343	0.112	-	0.032	0.392	0.093
<i>Cyperus rotundus</i>	0.047	-	0.003	0.021	0.002	-	0.061	0.030
FORBS								
<i>Micromeria biflora</i>	-	0.047	0.013	-	-	0.031	0.010	-
Total	0.396	1.566	1.581	1.308	0.439	1.680	1.701	1.325

in site I during sampling months fluctuated between 1.733-5.545. The table shows that the contribution of *C. montanus* (0.703-2.186 t/ha), *T. anathera* (0.240-1.050 t/ha) and *A. nepalensis* (0.512-0.993 t/ha) to the total belowground biomass of herbage was higher than other species. The contribution of forbs, legumes, and sedges to the total above and below ground biomass was <5 % (Table 21).

In site II, at middle elevation, aboveground biomass of herbs ranged from 0.832-3.274 having major contribution by *A. nepalensis* (0.660-0.262 t/ha), *T. anathera* (0.096-0.731 t/ha) and *C. martinii* (0.179-0.419 t/ha) to the total aboveground biomass. Total belowground biomass fluctuated between 1.136-2.722 t/ha. The table shows that the contribution of *T. anathera*, *A. nepalensis* and *C. martinii* to the total belowground biomass of herbage was higher than other species. Their contributions varied from 0.103-0.727, 0.199-0.517 and 0.097-0.270 (t/ha) respectively (Table 22).

Aboveground biomass (t/ha) of constituent herbs in site III, varied from 1.487-4.305. The contribution of *C. montanus* (0.603-1.539 t/ha), *A. nepalensis* (0.064-1.016 t/ha) and *T. anathera* (0.251-0.553 t/ha) were higher than other species. Total belowground biomass in site III, during sampling months fluctuated between 1.860-5.642 t/ha. The highest contribution in different months was by *C. montanus* (0.756-1.420 t/ha), *A. nepalensis* (0.102-1.741 t/ha) and *T. anathera* (0.312-0.704 t/ha) to the total belowground biomass. The results also explicate that less than 13% biomass was contributed by forbs, legumes, and sedges to the total above and belowground biomass (Table 23).

Comparing three sites at middle elevation, it was evident from the data that aboveground and belowground biomass was maximum in site I (Tables 21-23).

Aboveground biomass (t/ha) of herbs in site I, at higher elevation revealed that the biomass ranged from 1.167-3.534. The contributions of

Table 21: Monthly biomass (t/ha) of different herb species in grassland (Site I) at middle elevation (1300-1600m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	-	0.028	0.193	-	-	0.045	0.326
<i>Arundinella nepalensis</i>	0.437	-	0.816	0.463	0.512	-	0.993	0.863
<i>Chrysopogon fulvus</i>	0.034	0.035	0.365	0.009	0.059	0.094	0.364	0.024
<i>Chrysopogon montanus</i>	0.632	0.558	2.097	0.746	0.703	0.830	2.186	0.806
<i>Cymbopogon martinii</i>	0.088	0.133	0.043	0.005	0.073	0.067	0.064	0.013
<i>Dichanthium annulatum</i>	0.275	-	0.342	-	0.222	-	0.105	-
<i>Heteropogon contortus</i>	0.094	0.101	0.240	0.036	0.087	0.109	0.149	0.075
<i>Panicum maximum</i>	0.112	0.214	0.084	0.228	0.137	0.112	0.189	0.173
<i>Pennisetum orientale</i>	-	0.105	-	-	-	0.104	-	-
<i>Rottboellia exaltata</i>	-	0.116	0.295	0.039	-	0.080	0.127	0.143
<i>Setaria glauca</i>	-	0.011	0.054	-	-	0.029	0.073	-
<i>Themeda anathera</i>	0.423	0.236	1.120	0.651	0.542	0.240	1.05	0.526
<i>Urochloa panicoides</i>	0.025	0.019	0.038	0.187	0.040	0.020	0.056	0.034
SEDGES								
<i>Cyperus rotundus</i>	0.023	0.020	0.059	-	0.057	0.046	0.144	-
FORBS								
<i>Cissampelos pareira</i>	0.013	0.037	-	-	0.020	0.042	-	-
Total	2.156	1.585	5.581	2.557	2.452	1.773	5.545	2.983

Table 22: Monthly biomass (t/ha) of different herb species in chir pine forest (Site II) at middle elevation (1300-1600m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.023	-	0.182	0.161	0.205	-	0.237	0.163
<i>Arundinella nepalensis</i>	0.262	0.511	0.660	0.382	0.315	0.517	0.394	0.199
<i>Arundinella setosa</i>	-	-	0.030	-	-	-	0.111	-
<i>Chloris barbata</i>	-	-	0.008	-	-	-	0.011	-
<i>Chrysopogon montanus</i>	0.133	-	0.009	-	0.157	-	0.013	-
<i>Cymbopogon martinii</i>	0.179	0.240	0.350	0.419	0.254	0.214	0.270	0.097
<i>Digitaria Sanguinalis</i>	-	0.096	-	-	-	0.103	-	-
<i>Panicum maximum</i>	0.047	0.037	-	-	0.072	0.067	-	-
<i>Pennisetum orientale</i>	-	-	0.036	-	-	-	0.056	-
<i>Themeda anathera</i>	0.096	0.310	0.731	0.212	0.414	0.103	0.398	0.727
LEGUMES								
<i>Cassia mimosoides</i>	0.021	0.024	0.031	-	0.043	0.072	0.080	-
<i>Desmodium floribundum</i>	0.020	-	0.020	-	0.015	-	0.005	-
<i>Lespedza gerardiana</i>	0.051	0.069	-	-	0.040	0.052	-	-
SEDGES								
<i>Carex wallichiana</i>	-	-	1.242	1.144	-	-	1.305	1.060
FORBS								
<i>Cissampelos pareira</i>	-	0.004	-	-	-	0.008	-	-
<i>Micromeria biftora</i>	-	-	0.005	-	-	-	0.003	-
Total	0.832	1.291	3.304	2.318	1.515	1.136	2.883	2.246

Table 23: Monthly biomass (t/ha) of different herb species in mixed forest (Site III) at middle elevation (1300-1600m)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.033	0.052	0.825	0.038	0.047	0.065	0.297	0.042
<i>Arundinella nepalensis</i>	0.237	0.279	0.064	1.016	0.272	0.162	0.102	1.741
<i>Chrysopogon fulvus</i>	-	-	0.082	-	-	-	0.142	-
<i>Chrysopogon montanus</i>	0.603	0.704	1.539	1.120	0.756	0.945	1.848	1.420
<i>Cymbopogon martinii</i>	-	-	0.271	-	-	-	0.202	-
<i>Dichanthium annulatum</i>	-	-	0.308	-	-	-	0.140	-
<i>Heteropogon contortus</i>	0.033	0.053	0.470	0.054	0.075	0.040	0.543	0.065
<i>Panicum maximum</i>	0.132	-	0.007	0.190	0.177	-	0.070	0.059
<i>Panicum orientale</i>	-	0.027	-	-	-	0.056	-	-
<i>Rottboellia exaltata</i>	-	0.043	0.040	-	-	0.053	0.060	-
<i>Themeda anathera</i>	0.251	0.316	0.542	0.555	0.312	0.418	0.704	0.457
<i>Urochloa panicoides</i>	0.099	-	0.114	0.137	0.072	-	0.086	0.096
SEDGES								
<i>Carex wallichiana</i>	0.036	0.063	-	0.133	0.056	0.081	-	0.174
<i>Cyperus rotundus</i>	0.014	-	0.013	0.024	0.032	-	0.042	0.063
FORBS								
<i>Barleria aristata</i>	-	0.020	-	0.040	-	0.065	-	0.050
<i>Thymus serpyllum</i>	0.031	0.034	0.030	0.077	0.023	0.011	0.043	0.070
<i>Microstegium vagans</i>	0.013	0.020	-	-	0.037	0.033	-	-
<i>Tricholepis elongata</i>	-	0.071	-	-	-	0.050	-	-
<i>Viola pilosa</i>	0.005	-	-	0.009	0.001	-	-	0.005
Total	1.487	1.682	4.305	3.393	1.860	1.979	4.279	4.242

T. anathera, *P. maximum*, and *A. nepalensis* to the total aboveground biomass of herbage were higher than other species. Their respective aboveground biomass range was 0.268-0.786, 0.220-0.864 and 0.199-0.327 t/ha. Total belowground biomass in site I, during sampling months fluctuated between 0.823-4.393 t/ha. The data reveals that the contributions of *P. maximum*, *T. anathera* and *H. contortus* to the total belowground biomass of herbage were higher than other species. Their contributions varied from 0.279-1.386, 0.044-0.716 and 0.082-0.590 t/ha respectively. The contribution of forbs, legumes, and sedges to the total above and belowground biomass was 5 and 9% respectively (Table 24).

In site II aboveground biomass fluctuated from 0.922-2.580 t/ha. Contributions of dominant grasses like *T. anathera*, *A. nepalensis* and *C. montanus* to the aboveground biomass was 2.535, 1.733 and 0.707 t/ha, respectively. Likewise total belowground biomass (t/ha) in site II during sampling months varied between 1.408-2.712 with *T. anathera*, *A. nepalensis* and *C. montanus* being the major contributors to the belowground with biomass 2.441, 1.418 and 0.865 t/ha, respectively. The data obtained also indicates that contribution of forbs, legumes, and sedges to the total above and belowground biomass was less than 13 and 20% respectively (Table 25).

Aboveground biomass of herbs in site III, revealed that the biomass, ranged from 1.231-2.848 t/ha. The data shows that the contributions of *C. montanus*, *P. maximum* and *T. anathera* to the total aboveground biomass of herbage were higher than other species. Their respective aboveground biomass was 2.343, 1.794 and 1.493 t/ha. Total belowground biomass (t/ha) in site III during sampling months fluctuated between 1.271-3.618 t/ha. The contribution of *P. maximum*, *C. montanus* and *T. anathera* to the total belowground biomass of herbage was higher than other species. Their contribution varied from 0.182-1.688, 0.512-1.090 and 0.138 - 0.413 (t/ha) respectively. The results also reveal that

Table 24: Monthly biomass (t/ha) of different herb species in grassland (Site I) at higher elevation (1600m and above)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.010	0.012	0.074	0.145	0.031	0.020	0.112	0.151
<i>Arundinella nepalensis</i>	0.199	0.256	0.303	0.327	0.170	0.179	0.323	0.251
<i>Chrysopogon fulvus</i>	-	-	0.507	0.107	-	-	0.824	0.063
<i>Chrysopogon montanus</i>	0.182	0.190	0.383	-	0.240	0.167	0.227	-
<i>Dichanthium annulatum</i>	0.051	-	0.111	-	0.070	-	0.071	-
<i>Heteropogon contortus</i>	0.029	0.020	0.714	0.491	0.044	0.084	0.716	0.652
<i>Panicum maximum</i>	0.220	0.339	0.864	0.379	0.279	0.286	1.386	0.466
<i>Pennisetum orientale</i>	0.041	-	0.091	0.050	0.040	-	0.076	0.047
<i>Rottboellia exaltata</i>	0.012	-	0.016	-	0.030	-	0.010	-
<i>Setaria glauca</i>	-	0.011	0.039	-	-	0.005	0.009	0.007
<i>Themeda anathera</i>	0.373	0.712	0.268	0.786	0.252	0.082	0.249	0.590
SEDGES								
<i>Cyperus rotundus</i>	0.042	-	0.154	-	0.075	-	0.381	-
FORBS								
<i>Thymus serpyllum</i>	0.008	-	0.010	-	0.007	-	0.009	-
Total	1.167	1.540	3.534	2.285	1.238	0.823	4.393	2.227

Table 25: Monthly biomass (t/ha) of different herb species in chir pine forest (Site II) at higher elevation (1600m and above)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.030	0.010	0.120	0.050	0.040	0.010	0.120	0.050
<i>Arundinella nepalensis</i>	0.302	0.164	0.796	0.471	0.370	0.324	0.553	0.171
<i>Chrysopogon fulvus</i>	-	0.580	-	-	-	0.660	-	-
<i>Chrysopogon montanus</i>	0.091	-	0.260	0.356	0.242	-	0.312	0.311
<i>Dichanthium annulatum</i>	0.034	-	0.021	0.042	0.071	-	0.035	0.098
<i>Heteropogon contortus</i>	0.029	0.013	0.045	0.033	0.041	0.004	0.158	0.030
<i>Panicum colonum</i>	-	0.001	0.010	-	-	0.003	0.020	-
<i>Panicum maximum</i>	-	-	0.071	-	-	-	0.158	-
<i>Panicum orientale</i>	-	-	-	0.107	-	-	-	0.171
<i>Panicum sanguinale</i>	-	-	0.041	-	-	-	0.030	-
<i>Themeda anathera</i>	0.302	0.595	1.099	0.539	0.364	0.308	1.054	0.715
<i>Urochloa panicoides</i>	-	-	-	0.176	-	-	-	0.277
LEGUMES								
<i>Cassia mimosoides</i>	0.017	0.134	-	0.028	0.029	0.121	-	0.037
<i>Indigofera pulchella</i>	0.021	-	-	0.046	0.051	-	-	0.119
<i>Lespedeza gerardiana</i>	0.023	0.003	0.032	-	0.020	0.003	0.030	-
SEDGES								
<i>Carex wallichiana</i>	0.005	-	0.010	0.033	0.004	-	0.012	0.030
<i>Cyperus esculentus</i>	-	0.034	0.072	0.021	-	0.024	0.050	0.018
<i>Cyperus rotundus</i>	0.068	-	-	0.108	0.176	-	0.160	-
FORBS								
<i>Barleria aristata</i>	-	-	0.003		-	-	-	0.006
<i>Thymus serpyllum</i>	-	-	-	0.014	-	-	0.020	-
Total	0.922	1.534	2.580	2.024	1.408	1.457	2.712	2.033

contribution of forbs, legumes, and sedges to the total above and belowground biomass was less than 5 and 12 % respectively (Table 26).

A perusal of data in Table 27 revealed that, in site IV, total aboveground biomass ranged from 1.079-2.938 t/ha. The data revealed that 0.418-1.150, 0.080-0.973 and 0.224-0.604 (t/ha) was contributed by *T. anathera*, *A. mutica* and *A. nepalensis* to the total aboveground biomass, respectively. Likewise total belowground biomass (t/ha) in site IV fluctuated between 1.469-3.068. The contributions of *T. anathera*, *A. nepalensis* and *A. mutica* to the total belowground biomass of herbage were higher than other species. Their contributions were: 0.350-0.876, 0.212-0.616 and 0.075-0.498 t/ha, respectively. Forbs, legumes, and sedges contributed the total above and belowground biomass less than 16%.

Aboveground biomass of herbs in site V revealed that the biomass ranged from 1.443-1.931 t/ha. The table shows that the contributions of *C. esculentus* (0.281-0.660 t/ha), *P. cretica* (0.096-0.318 t/ha) and *C. longieroris* (0.195-0.272 t/ha) to the total aboveground biomass of herbage were higher than other species. Total belowground biomass (t/ha) ranged from 1.665-2.479. The data reveals that the contribution of *P. cretica* (0.216-0.530 t/ha), *P. discretum* (0.285-0.530 t/ha) and *F. rigidula* (0.164-0.503 t/ha) was higher than other species. Grasses contributed less than 12% to the above and belowground biomass (Table 28).

Comparing five sites at higher elevation, it was evident from the (Tables 24-28) that above and belowground biomass was higher in site I and least in site V.

Statistical analysis of data revealed that total biomass of herbage was significantly higher in grassland. The effect of elevation on biomass of herbage revealed that it was maximum at middle elevation, which was statistically at par with lower elevation. Minimum biomass in grasslands was observed at higher elevation whereas maximum at middle elevation.

Table 26: Monthly biomass (t/ha) of different herb species in mixed forest (Site III) at higher elevation (1600m and above)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.149	-	-	0.224	0.102	-	-	0.118
<i>Arundinella nepalensis</i>	0.017	0.018	0.117	0.108	0.031	0.058	0.138	0.070
<i>Chrysopogon fulvus</i>	-	-	-	0.014	-	-	-	0.022
<i>Chrysopogon montanus</i>	0.446	0.671	0.593	0.633	0.512	1.090	0.664	0.693
<i>Dichanthium annulatum</i>	-	0.079	-	0.036	-	0.091	-	0.117
<i>Heteropogon contortus</i>	-	0.151	0.421	0.062	-	0.163	0.370	0.052
<i>Panicum maximum</i>	0.149	0.159	1.160	0.326	0.182	0.188	1.668	0.479
<i>Pennisetum orientale</i>	-	0.237	0.163	0.111	-	0.162	0.142	0.110
<i>Rottboellia exaltata</i>	0.039	0.051	-	-	0.027	0.031	-	-
<i>Themeda anathera</i>	0.378	0.592	0.243	0.280	0.300	0.138	0.181	0.413
<i>Urochloa panicoides</i>	-	-	0.039	-	-	-	0.025	-
LEGUMES								
<i>Indigofera pulchella</i>	0.013	-	0.016	-	0.011	-	0.013	-
SEDGES								
<i>Cyperus rotundus</i>	0.040	-	0.084	0.044	0.133	-	0.395	0.182
FORBS								
<i>Berleria aristata</i>	-	-	0.012	-	-	-	0.022	-
Total	1.231	1.958	2.848	1.838	1.298	1.921	3.618	2.256

Table 27: Monthly biomass (t/ha) of different herb species in ban-oak forest (Site IV) at higher elevation (1600m and above)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	0.080	0.080	0.329	0.973	0.075	0.078	0.288	0.498
<i>Arundinella nepalensis</i>	0.224	-	0.604	0.214	0.212	-	0.616	0.264
<i>Chrysopogon fulvus</i>	0.149	-	0.282	0.089	0.162	-	0.306	0.112
<i>Chrysopogon montanus</i>	0.112	0.090	0.061	0.457	0.132	0.169	0.090	0.487
<i>Dichanthium annulatum</i>	0.115	-	0.273	0.195	0.141	-	0.252	0.190
<i>Digitaria sanguinalis</i>	0.003	-	-	0.005	0.007	-	-	0.006
<i>Heteropogon contortus</i>	0.054	0.094	0.134	0.041	0.081	0.230	0.177	0.060
<i>Panicum maximum</i>	-	0.107	-	-	-	0.057	-	-
<i>Panicum orientale</i>	-	-	-	0.069	-	-	-	0.058
<i>Panicum sanguinale</i>	0.013	-	-	0.026	0.030	-	-	0.030
<i>Setaria glauca</i>	-	-	-	0.005	-	-	-	0.012
<i>Themeda anathera</i>	0.303	0.418	1.150	0.411	0.350	0.626	0.876	0.452
<i>Urochloa panicoides</i>	0.029	0.145	0.037	-	0.048	0.208	0.094	-
LEGUMES								
<i>Cassia mimosoides</i>	-	0.130	0.009	-	-	0.134	0.024	-
<i>Desmodium floribundum</i>	0.010	0.015	0.011	-	0.036	0.053	0.048	-
<i>Indigofera pulchella</i>	0.001	-	0.003	-	0.020	-	0.065	-
SEDGES								
<i>Carex wallichiana</i>	-	-	0.006	-	-	-	0.020	-
<i>Cyperus esculentus</i>	0.006	-	0.007	-	0.004	-	0.006	-
<i>Cyperus rotundus</i>	0.015	-	0.019	0.054	0.073	-	0.162	0.172
FORBS								
<i>Microstegium vagans</i>	0.149	-	0.012	-	0.098	-	0.039	-
<i>Thymus serpyllum</i>	-	-	0.001	-	-	-	0.005	-
Total	1.263	1.079	2.938	2.539	1.469	1.555	3.068	2.341

Table 28: Monthly biomass (t/ha) of different herb species in deodar forest (Site V) at higher elevation (1600m and above)

Plant categories/ species	Aboveground biomass				Belowground biomass			
	months				months			
GRASSES	July	Aug	Sep	Oct	July	Aug	Sep	Oct
<i>Apluda mutica</i>	-	0.021	-	0.019	-	0.058	-	0.036
<i>Avena sterilis</i>	-	-	0.041	0.112	-	-	0.031	0.105
<i>Digitaria sanguinalis</i>	0.021	0.066	0.085	0.076	0.045	0.149	0.036	0.070
<i>Panicum colonum</i>	0.010	-	0.020	0.013	0.022	-	0.043	0.031
<i>Urochloa panicoides</i>	0.011	0.016	0.086	-	0.033	0.056	0.048	-
SEDGES								
<i>Carex longieroris</i>	0.225	-	0.195	0.272	0.230	-	0.219	0.240
<i>Cyperus esculentus</i>	0.281	0.371	0.660	0.467	0.310	0.310	0.730	0.841
<i>Fimbristylis rigidula</i>	0.236	0.400	0.176	0.210	0.295	0.503	0.164	0.183
FORBS								
<i>Arthyrium schimpeni</i>	0.063	-	0.142	0.050	0.092	-	0.165	0.178
<i>Microstegium vaganus</i>	0.170	0.200	-	0.270	0.070	0.088	-	0.080
<i>Malaxis acumenata</i>	0.032	-	0.260	0.059	0.047	-	0.239	0.019
<i>Polystichum discretum</i>	0.201	0.251	0.096	-	0.285	0.530	0.365	-
<i>Pteris cretica</i>	0.169	0.251	0.096	0.318	0.216	0.530	0.365	0.401
<i>Thalictrum foliolosum</i>	0.024	-	0.074	0.036	0.020	-	0.074	0.021
<i>Viola pilosa</i>	-	-	-	0.004	-	-	-	0.018
Total	1.443	1.576	1.931	1.893	1.665	2.224	2.479	2.192

However, biomass in chir pine forests decreased with the increase in elevation, while biomass in mixed forests was higher at middle elevation which was at par with lower elevation (Table 29).

Table 29. Interaction between biomass of herbs in different grassland /forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	9.62	7.16	8.17	8.50
Middle (1300-1600)	11.13	6.04	8.58	8.58
Higher (1600 and above)	7.95	5.29	6.55	6.60
Mean	9.55	6.16	7.94	

		SE _±	CD _{0.05}
T	=	0.49	1.05
F	=	0.49	1.05
TxF	=	0.86	1.82

Phytosociology and biomass of shrubs

The result of the phytosociological studies of different shrub species and distribution of their biomass (t/ha) among their components in different sites at three elevations are given in Tables 30-32 and described as under:-

The characteristics of shrubs at lower elevation (900-1300m) revealed that, in site I, basal area (m²/ha) and density (number of plants /ha) of shrubs ranged from 0.006 (*C. wallichiana*) to 0.102 (*W. fruticosa*) and 100 (*C. wallichiana*) to 500 (*W. fruticosa*), respectively. *I. gerardiana* also exhibited higher basal area of 0.085 m²/ha while *C. microphylla* and *L. camara* showed higher density of 200/ha each. The dominant shrub with highest IVI (77.26) in this site was *W. fruticosa* (16.42) and co-dominant shrub was *I. gerardiana* with IVI as 54.70 while *C. wallichiana* was the rare shrub with minimum IVI as 16.42.

Branch biomass of shrubs, in site I, ranged from 0.020 (*C. wallichiana*) to 3.925 (*W. fruticosa*) t/ha. Leaf biomass varied from 0.010 (*C. wallichiana*) to 0.357 (*W. fruticosa*) t/ha. The aboveground biomass

fluctuated from 0.029 (*C. wallichiana*) to 4.282 (*W. fruticosa*) t/ha. Belowground biomass of shrubs showed a range of 0.096 (*C. wallichiana*) 0.191 to (*W. fruticosa*)t/ha. The total biomass of individual shrub ranged from 0.125 t/ha (*C. wallichiana*) 4.473 to (*W. fruticosa*) (Table 30).

At lower elevation, in site II, the basal area of shrubs was maximum (0.126 m²/ha) for *C. microphylla* and minimum (0.004 m²/ha) for *Berberis lycium*. Density (plants/ha) of different shrubs ranged from 50 (*H. suaveolens*) to 600 (*C. microphylla*). The dominant shrub with maximum IVI value (84.28) was *C. microphylla* and *H. suaveolens* was the rare species with minimum IVI value (12.23).

The branch biomass of different shrubs in this site ranged from 0.006 (*B. lycium*) to 0.089 (*C. wallichiana*) t/ha. Leaf biomass was recorded maximum (0.074 t/ha) for *C. microphylla* and it was minimum (0.002 t/ha) for *D. cannabina*. Aboveground biomass of shrubs ranged from 0.010 (*B. lycium*) 0.149 to (*C. microphylla*) t/ha. Belowground biomass shrubs varied from 0.031 to 0.654 t/ha. Maximum belowground biomass was recorded for *R. moschata* and minimum for *D. cannabina*. Total biomass of individual shrubs ranged from 0.066 (*H. suaveolens*) 0.688 to (*R. moschata*) t/ha (Table 30).

In site III, at lower elevation, basal area of different shrubs fluctuated from 0.001 (*M. rubicaulis*) to 0.347 m²/ha (*L. camara*). Their density ranged from 50 (*C. microphylla*) to 850 m²/ha (*L. camara*). *L. camara* was the dominant shrub with maximum IVI value as 110.90 and *Cotoneaster microphylla* was the rare species with minimum IVI value (10.78).

Branch biomass values for different shrubs in this site ranged from 0.002 (*M. rubicaulis*) to 1.711 (*L. camara*) t/ha. Leaf biomass of shrubs species fluctuated between 0.007 (*C. microphylla*) to 0.498 *C. carandas* t/ha. Aboveground biomass of shrubs showed that it was maximum 2.047

Table: 30 Phytosociology and components biomass (t/ha) of shrub species in sites I-IV at lower elevation (900-1300m)

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density/ (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass { A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site I								
<i>Carissa carandas</i>	0.018	250	36.98	0.034	0.040	0.074	0.092	0.166
<i>Carypteris wallichiana</i>	0.006	100	16.42	0.020	0.010	0.029	0.096	0.125
<i>Cotoneaster microphylla</i>	0.035	200	30.82	0.041	0.028	0.069	0.147	0.216
<i>Indigofera gerardiana</i>	0.085	350	54.70	0.485	0.253	0.738	0.336	1.074
<i>Lantana camara</i>	0.038	200	41.05	0.102	0.062	0.164	0.119	0.282
<i>Osyris arborea</i>	0.027	300	42.77	0.048	0.031	0.079	0.224	0.302
<i>Woodfordia fruticosa</i>	0.102	500	77.26	3.925	0.357	4.282	0.191	4.473
Total	0.311	1900	300	4.653	0.780	5.433	1.204	6.637
Site II								
<i>Berberis lycium</i>	0.004	300	20.41	0.006	0.004	0.010	0.064	0.073
<i>Carissa carandas</i>	0.018	550	42.31	0.050	0.052	0.102	0.113	0.215
<i>Carypteris wallichiana</i>	0.033	350	40.27	0.089	0.046	0.135	0.154	0.289
<i>Cotoneaster microphylla</i>	0.126	600	84.28	0.075	0.074	0.149	0.186	0.335
<i>Daphne cannabina</i>	0.016	100	17.03	0.035	0.002	0.037	0.031	0.068
<i>Hamiltonia suaveolens</i>	0.008	50	12.23	0.022	0.007	0.028	0.038	0.066
<i>Lantana camara</i>	0.009	150	16.25	0.026	0.020	0.046	0.045	0.091
<i>Lonicera quinquelocularis</i>	0.014	100	16.35	0.048	0.030	0.077	0.093	0.170
<i>Pyrus pashia</i>	0.008	200	24.99	0.027	0.021	0.047	0.123	0.170
<i>Rosa moschata</i>	0.035	150	25.89	0.020	0.014	0.034	0.654	0.688
Total	0.272	2550	300	0.395	0.268	0.663	1.501	2.164

Table contd...

Table: 30. Contd....

Species	Phytosociology				Biomass			
	Basal area (m ² /ha)	Density/ (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site III								
<i>Carissa carandas</i>	0.211	600	77.78	1.300	0.498	1.798	0.467	2.264
<i>Caryopteris wallichiana</i>	0.020	100	16.15	0.106	0.050	0.156	0.057	0.213
<i>Cotoneaster microphylla</i>	0.001	50	10.78	0.008	0.007	0.015	0.012	0.027
<i>Lantana camara</i>	0.347	850	110.90	1.711	0.337	2.047	0.446	2.493
<i>Mimosa rubicaulis</i>	0.001	150	15.25	0.002	0.002	0.004	0.012	0.016
<i>Pyrus pashia</i>	0.011	100	22.90	0.060	0.015	0.075	0.028	0.102
<i>Woodfordia fruticosa</i>	0.006	150	16.15	0.017	0.012	0.029	0.008	0.037
<i>Ziziphus Jujuba</i>	0.027	200	30.08	0.085	0.034	0.118	0.354	0.472
Total	0.624	2200	300	3.287	0.953	4.240	1.383	5.623
Site IV								
<i>Asparagus adscendens</i>	0.001	100	8.97	0.002	0.002	0.004	0.040	0.043
<i>Berberis lycium</i>	0.009	350	20.70	0.020	0.011	0.031	0.013	0.044
<i>Carissa carandas</i>	0.001	50	8.36	0.002	0.002	0.003	0.002	0.005
<i>Eleaegnus umbellata</i>	0.003	150	9.79	0.005	0.001	0.006	0.005	0.010
<i>Hamiltonia suaveolens</i>	0.402	4066	167.60	1.288	0.264	1.552	0.600	2.153
<i>Indigofera gerardiana</i>	0.014	900	19.96	0.120	0.061	0.180	0.117	0.297
<i>Mimosa rubicaulis</i>	0.001	150	17.23	0.003	0.001	0.004	0.009	0.013
<i>Myrsine africana</i>	0.003	100	9.21	0.005	0.001	0.006	0.004	0.009
<i>Osyris arborea</i>	0.011	350	13.26	0.008	0.026	0.034	0.105	0.139
<i>Rubus ellipticus</i>	0.015	650	24.95	0.045	0.056	0.101	0.089	0.190
Total	0.460	6866	300	1.498	0.425	1.921	0.984	2.903

Where: Site I - Grassland, Site II - Chir pine forest, Site III - Mixed forest and Site IV - Ban-oak forest

t/ha for *L. camara* and minimum 0.004 t/ha for *M. rubicaulis*. Likewise belowground biomass was maximum 0.467 t/ha for *C. carandas* and minimum 0.008 t/ha for *W. fruticosa*. Total biomass of individual shrub species ranged from 0.016 (*M. rubicaulis*) 2.493 to (*L. camara*) t/ha (Table 30).

In site IV, at lower elevation, basal area shrubs varied from 0.001 to 0.402 m²/ha. Maximum basal area was recorded for *H. suaveolens* and minimum for *M. rubicaulis*, *A. adscendens* and *C. carandas*. Density of different shrubs ranged from 50 (*C. carandas*) to 4066 (*H. suaveolens*) plants/ha. *H. suaveolens* was the dominant shrub with IVI value of 167.58 and *C. carandas* was the rare species with IVI of 8.36.

Branch biomass of shrubs fluctuated from 0.002 (*A. adscendens* & *C. carandas*) to 1.288 (*H. suaveolens*) t/ha. Leaf biomass of shrubs was maximum (0.264) for *H. suaveolens* and minimum 0.001 t/ha for *M. rubicaulis*, *E. umbellata* and *M. africana*. Aboveground biomass of individual shrubs ranged from 0.003 (*C. carandas*) to 1.552 (*H. suaveolens*) whereas, belowground biomass varied from 0.002 (*C. carandas*) to 0.600 (*H. suaveolens*) t/ha. Total biomass different shrubs fluctuated between 0.005 (*E. umbellata*) to 2.153 (*H. suaveolens*) t/ha (Table 30).

Comparing the four sites at lower elevation it was evident from the data in Table 30 that the density of shrubs was highest in site IV and basal area was maximum in site III. However, the aboveground biomass and total biomass of shrubs was highest in site I.

A perusal of Table 31 on phytosociological record of different shrub species and distribution of their biomass among their components in different sites at middle elevation (1300 – 1600 m) revealed that, in site I, *H. suaveolens* had maximum basal area (0.079 m²/ha) followed by *C. carandas* (0.046 m²/ha), which also had maximum density (500plants/ha). *H. suaveolens* was the dominant species with IVI value of 69.57.

Whereas, *O. arborea* recorded minimum basal area (0.010 m²/ha), density (50 plants/ha) and was the rare species with IVI of 18.32.

Branch biomass of the shrubs in this site (Table 31) fluctuated between 0.043 t/ha and (*B. lycium*) 0.266 t/ha (*H. suaveolens*). Leaf biomass was highest for *C. carandus* (0.068 t/ha) and lowest for *B. lycium* (0.006 t/ha). Aboveground biomass of the different species differed in a range of 0.041 t/ha (*O. arborea*) and 0.233 t/ha (*A. adscendens*). Belowground biomass was highest for *W. fruticosa* (0.257 t/ha) and lowest for *O. arborea* (0.008 t/ha). Total biomass of individual shrubs was found to vary between 0.049 t/ha (*O. arborea*) and 0.715 t/ha (*H. suaveolens*).

In site II, at middle elevation, numeric values of basal area (m²/ha) of different species revealed that *L. lanceolata* showed highest value (0.351) and minimum value (0.002) was recorded for *C. nepalensis* and *O. arborea*. Highest density (plants ha) was observed in *R. ellipticus* (2300) and minimum (50) in *M. strobilifera*. The IVI of different species explicated that *R. ellipticus* (62.81) was the dominant species while *L. lanceolata* (57.41) and *C. carandas* (47.79) can be considered as co-dominant species. *B. lycium*, *W. fruticosa* and *M. strobilifera* had low IVI values to be considered as rare species in this site.

Branch biomass (t/ha) of different shrubs, in site II, fluctuated between 0.001 (*W. fruticosa* and *O. arborea*) to 1.106 (*L. lanceolata*). Leaf biomass was recorded maximum for *C. carandas* (0.414 t/ha) and minimum for *W. fruticosa* (0.001 t/ha). Aboveground biomass was recorded maximum for *C. carandas* (1.260 t/ha) and minimum for *W. fruticosa* (0.002 t/ha). Belowground biomass of different shrubs ranged from 0.003 (*W. fruticosa*) to 1.004 (*L. lanceolata*) t/ha. Total biomass of individual shrubs revealed that it was maximum (2.231 t/ha) for *L. lanceolata* and minimum (0.005 t/ha) for *W. fruticosa* (Table 31).

Table 31: Phytosociology and components biomass (t/ha) of shrub species in sites I, II & III at middle elevation (1300-1600 m)

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density / (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site I								
<i>Asparagus adscendens</i>	0.025	250	47.36	0.175	0.058	0.233	0.077	0.309
<i>Berberis lycium</i>	0.012	50	19.49	0.043	0.006	0.049	0.229	0.277
<i>Carissa carandas</i>	0.046	500	59.24	0.092	0.068	0.160	0.145	0.305
<i>Hamiltonia suaveolens</i>	0.079	400	69.57	0.266	0.037	0.302	0.413	0.715
<i>Indigofera geradiana</i>	0.024	450	57.77	0.055	0.046	0.100	0.082	0.182
<i>Osyris arborea</i>	0.010	50	18.32	0.028	0.013	0.041	0.008	0.049
<i>Woodfordia fruticosa</i>	0.019	150	28.24	0.062	0.044	0.106	0.257	0.363
Total	0.216	1850	300	0.719	0.270	0.989	1.209	2.199
Site II								
<i>Berberis lycium</i>	0.010	150	9.51	0.026	0.013	0.039	0.016	0.055
<i>Carissa carandas</i>	0.202	850	47.79	0.846	0.414	1.260	0.606	1.866
<i>Coriaria nepalensis</i>	0.002	150	8.61	0.004	0.005	0.008	0.043	0.051
<i>Cotoneaster microphylla</i>	0.062	600	28.08	0.138	0.049	0.187	0.068	0.254
<i>Lantana camara</i>	0.028	900	28.29	0.041	0.056	0.097	0.024	0.120
<i>Leptodermis lanceolata</i>	0.351	750	57.41	1.016	0.211	1.227	1.004	2.231
<i>Meriandra strobilifera</i>	0.008	50	7.92	0.020	0.005	0.024	0.017	0.041
<i>Myrsine africana</i>	0.024	1000	23.03	0.034	0.026	0.059	0.023	0.082
<i>Osyris arborea</i>	0.002	150	8.57	0.001	0.003	0.004	0.018	0.021
<i>Rosa moschata</i>	0.014	150	10.01	0.033	0.006	0.038	0.041	0.079
<i>Rubus ellipticus</i>	0.157	2300	62.81	0.398	0.258	0.655	0.277	0.932
<i>Woodfordia fruticosa</i>	0.003	100	7.97	0.001	0.001	0.002	0.003	0.005
Total	0.863	7150	300	2.554	1.044	3.598	2.137	5.735

Table contd...

Table: 31. Contd....

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density / (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site III								
<i>Asparagus adscendens</i>	0.055	900	28.80	0.138	0.092	0.230	0.021	0.250
<i>Berberis lycium</i>	0.277	150	33.10	0.041	0.019	0.060	0.015	0.075
<i>Carissa carandas</i>	0.047	700	24.71	1.738	0.672	2.410	0.555	2.965
<i>Caryopteris wallichiana</i>	0.136	300	26.51	0.209	0.115	0.324	0.224	0.547
<i>Indigofera gerardiana</i>	0.106	800	31.92	0.238	0.111	0.349	0.398	0.746
<i>Justicia adhatoda</i>	0.035	300	12.60	0.041	0.024	0.065	0.027	0.092
<i>Lantana camara</i>	0.053	750	26.15	0.131	0.087	0.217	0.085	0.302
<i>Leucas lanata</i>	0.097	650	24.27	0.282	0.082	0.363	0.193	0.556
<i>Meriandra strobilifera</i>	0.029	150	9.55	0.021	0.016	0.037	0.053	0.089
<i>Mimosa rubicaulis</i>	0.115	400	26.24	0.522	0.121	0.643	0.372	1.015
<i>Myrsine africana</i>	0.019	400	17.09	0.024	0.022	0.046	0.034	0.079
<i>Osyris arborea</i>	0.005	50	5.60	0.007	0.006	0.013	0.038	0.051
<i>Pyrus pashia</i>	0.027	100	8.52	0.029	0.009	0.038	0.026	0.064
<i>Rabolasia rugosus</i>	0.035	300	16.93	0.134	0.059	0.193	0.097	0.290
<i>Woodfordia fruticosa</i>	0.022	100	8.04	0.013	0.031	0.044	0.034	0.078
Total	1.056	6050	300	3.562	1.464	5.026	2.170	7.196

Where: Site I - Grassland, Site II - Chir pine forest, Site III - Mixed forest

The phytosociology of constituent shrubs, (Table 31) in site III, revealed that *B. lycium* had highest ($0.277 \text{ m}^2/\text{ha}$) and *O. arborea* lowest ($0.005 \text{ m}^2/\text{ha}$) basal area. *A. adscendens* had highest density (900 plants/ha) and *O. arborea* had lowest density of 50 plants/ha. *O. arborea* was the dominant shrub with IVI as 50.60 and *B. lycium*, *I. gerardiana*, *A. adscendens* and *C. wallichiana* were the co-dominant shrubs with IVI values as 33.10, 31.92, 28.80 and 26.51, respectively.

A perusal of Table 31 revealed that, branch biomass (t/ha) of constituent shrubs varied from 0.007 (*O. arborea*) to 1.738 (*C. carandas*). Leaf biomass was recorded highest for *C. carandas* (0.672 t/ha) and lowest for *O. arborea* (0.006 t/ha). Aboveground biomass of the individual shrubs ranged from 0.013 (*O. arborea*) to 2.410 (*C. carandas*) t/ha. Belowground biomass varied from 0.013 t/ha (*P. pashia*) to 0.555 t/ha for (*C. carandas*). Total biomass of the individual shrubs in this site fluctuated between 0.075 (*O. arborea*) to 2.965 (*C. carandas*) t/ha. Maximum contribution to total biomass was by *C. carandas* (41.2%) followed by *M. rubicaulis* (14.1%).

Comparing the three sites at middle elevation, it was evident from the data in Table 31 that the density of shrubs was highest in site II and basal area was maximum in site III. However, the total biomass of shrubs was highest in site III.

At higher elevation (1600m and above) the phytosociology and biomass records of different shrubs is presented in Table 32.

In site I, basal area of shrubs ranged from 0.001 (*J. officinale*) to 0.172 (*R. moschata*) m^2/ha . *I. gerardiana* exhibited the highest density ($550 \text{ m}^3/\text{ha}$) and *R. moschata* had minimum density ($50 \text{ m}^3/\text{ha}$). *I. gerardiana* was the dominant shrub with highest IVI value (75.61) and *J. officinale* was the rare shrub with least IVI value (10.98).

Branch biomass values of different shrubs ranged from 0.007 (*I. dosua*) to 0.819 (*I. gerardiana*) t/ha. Leaf biomass of different shrubs fluctuated from 0.003 (*J. officinale* and *R. moschata*) to 0.255 (*I. gerardiana*) t/ha. Aboveground biomass was maximum (0.559 t/ha) in *H. suaveolens* and minimum (0.004 t/ha) in *J. officinale*. The belowground values of shrubs varied between 0.012 (*R. moschata*) to 0.797 (*I. gerardiana*) t/ha. Total biomass of individual shrubs was maximum (1.871 t/ha) for *I. gerardiana* and minimum (0.024 t/ha) for *R. moschata* (Table 32).

In site II, basal area of different shrubs species ranged from 0.001 (*P. utilis*) to 0.264 (*H. suaveolens*) m²/ha. Density of *M. africana* was highest (700 plants/ha) while *D. cannabina* and *P. utilis* had the least density of 50 plants/ha. *H. suaveolens* was the dominant shrub with highest IVI value (51.66) and *P. utilis* was the rare shrub with lowest IVI value (6.72).

Branch biomass of different shrubs ranged from 0.006 (*P. utilis*) to 0.866 (*O. arborea*) t/ha. Leaf biomass of shrubs revealed that it was highest (0.340 t/ha) in *W. fruticosa* and least (0.002 t/ha) in *P. utilis*. Aboveground biomass of different shrubs fluctuated between 0.021 (*D. cannabina*) to 1.169 (*O. arborea*) t/ha. Belowground biomass of individual shrubs ranged from 0.003 (*P. utilis*) to 0.459 (*L. lanceolata*) t/ha. Total biomass of different shrubs revealed that it was highest (1.184 t/ha) for *I. gerardiana* and lowest (0.010 t/ha) for *P. utilis* (Table 32).

A perusal of the data in Table 32 revealed that, in site III, the maximum value for basal area (0.497 m²/ha) was recorded in *I. gerardiana* and least (0.038 m²/ha) in *P. pashia*. Density was highest (800 plants/ha) for *I. gerardiana* and least (150 plants/ha) for *H. helix*. *I. gerardiana* was the dominant shrub with highest IVI value of 87.24 and *H. helix* was the rare species with lowest IVI value of 12.58.

Table 32: Phytosociology and components biomass (t/ha) of shrub species in sites I-V at higher elevation (1600m and above)

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density/ (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site I								
<i>Berberis lycium</i>	0.097	300	49.38	0.439	0.087	0.525	0.079	0.604
<i>Cotoneaster microphylla</i>	0.064	200	30.01	0.232	0.052	0.283	0.151	0.434
<i>Daphne cannabina</i>	0.042	150	23.42	0.194	0.052	0.246	0.068	0.313
<i>Hamiltonia suaveolens</i>	0.117	400	58.08	0.457	0.103	0.559	0.300	0.859
<i>Indigofera dosua</i>	0.003	50	11.28	0.007	0.003	0.010	0.021	0.030
<i>Indigofera geradiana</i>	0.172	550	75.61	0.819	0.255	1.074	0.797	1.871
<i>Jasminum officinale</i>	0.001	50	10.98	0.004	0.001	0.004	0.012	0.016
<i>Rabolasia rugosus</i>	0.039	300	30.15	0.154	0.041	0.194	0.068	0.262
<i>Rosa moschata</i>	0.002	50	11.10	0.010	0.003	0.012	0.012	0.024
Total	0.537	2050	300	2.313	0.597	2.906	1.507	4.412
Site II								
<i>Asparagus adscendens</i>	0.022	150	19.39	0.041	0.026	0.067	0.217	0.284
<i>Berberis lycium</i>	0.066	80	15.88	0.123	0.049	0.172	0.404	0.576
<i>Daphne cannabina</i>	0.003	40	6.94	0.018	0.003	0.021	0.007	0.028
<i>Hamiltonia suaveolens</i>	0.264	450	51.66	1.022	0.122	1.144	0.362	1.506
<i>Indigofera gerardiana</i>	0.012	150	13.12	0.036	0.026	0.062	0.168	0.230
<i>Leptodermis lanceolata</i>	0.134	120	29.34	0.453	0.043	0.496	0.459	0.955
<i>Myrsine africana</i>	0.066	550	35.82	0.104	0.047	0.151	0.143	0.294
<i>Osyris arborea</i>	0.169	450	43.48	0.680	0.203	0.883	0.366	1.249
<i>Plectranthus rugosus</i>	0.015	400	25.37	0.024	0.025	0.049	0.014	0.063
<i>Prinsepia utilis</i>	0.001	50	6.72	0.006	0.002	0.008	0.003	0.011
<i>Pyrus pashia</i>	0.057	100	13.61	0.362	0.052	0.414	0.054	0.468
<i>Woodfordia fruticosa</i>	0.188	250	38.67	0.671	0.140	0.811	0.322	1.133
Total	0.997	2790	300	3.540	0.738	4.278	2.519	6.797

Table contd...

Table: 32. Contd....

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density/ (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site III								
<i>Berberis lycium</i>	0.089	450	35.65	0.231	0.098	0.329	0.215	0.544
<i>Cotoneaster microphylla</i>	0.087	600	39.46	0.220	0.064	0.284	0.145	0.429
<i>Hamiltonia suaveolens</i>	0.123	450	39.17	1.297	0.365	1.662	0.382	2.044
<i>Hedera helix</i>	0.013	150	12.58	0.028	0.015	0.043	0.018	0.061
<i>Indigofera gerardiana</i>	0.497	700	87.24	2.464	0.510	2.974	0.981	3.955
<i>Myrsine africana</i>	0.058	550	28.00	0.104	0.025	0.129	0.506	0.635
<i>Pyrus pashia</i>	0.038	350	27.71	0.152	0.036	0.188	0.284	0.472
<i>Rabolasia rugosus</i>	0.062	350	30.19	0.232	0.096	0.328	0.122	0.450
Total	0.967	3600	300	4.728	1.209	5.937	2.653	8.590
Site IV								
<i>Berberis lycium</i>	0.405	400	66.17	0.289	0.116	0.405	0.425	0.829
<i>Coriaria nepalensis</i>	0.001	50	7.40	0.003	0.005	0.007	0.001	0.008
<i>Cotoneaster microphylla</i>	0.028	400	17.78	0.096	0.021	0.117	0.102	0.219
<i>Hamiltonia suaveolens</i>	0.126	450	36.09	0.479	0.105	0.584	0.372	0.956
<i>Indigofera dosua</i>	0.096	800	53.70	0.390	0.157	0.547	0.584	1.131
<i>Indigofera gerardiana</i>	0.092	550	34.35	0.957	0.187	1.144	0.285	1.428
<i>Myrsine africana</i>	0.125	700	34.96	0.727	0.122	0.849	0.198	1.046
<i>Pyrus pashia</i>	0.004	200	17.19	0.055	0.008	0.063	0.040	0.102
<i>Rubus ellipticus</i>	0.010	450	23.08	0.053	0.053	0.106	0.035	0.140
<i>Vitis himalayana</i>	0.008	100	9.29	0.031	0.012	0.043	0.016	0.059
Total	0.896	4150	300	3.078	0.784	3.862	2.055	5.917

Table contd...

Table: 32. Contd....

Species	Phytosociology				Biomass			
	Basal area (m ² / ha)	Density/ (ha)	I.V.I	Branch biomass (a)	Leaf biomass (b)	Above ground biomass {A=(a+b)}	Below ground biomass (B)	Total biomass (A+B)
Site IV								
<i>Berberis lycium</i>	0.182	700	34.42	0.931	0.199	1.130	0.980	2.110
<i>Cornus capitata</i>	0.016	100	8.54	0.063	0.003	0.066	0.102	0.168
<i>Cotoneaster microphylla</i>	0.014	250	9.37	0.029	0.008	0.037	0.068	0.105
<i>Hedera helix</i>	0.078	950	28.28	0.140	0.095	0.235	0.101	0.336
<i>Myrsine africana</i>	0.360	2850	72.99	0.864	0.470	1.334	1.960	3.294
<i>Prinsepia utilis</i>	0.311	2100	64.27	0.405	0.501	0.906	0.329	1.235
<i>Rosa moschata</i>	0.002	100	7.51	0.014	0.003	0.017	0.023	0.040
<i>Sarcococca saligna</i>	0.330	1550	57.36	0.605	0.352	0.957	0.412	1.369
<i>Wikstroemia canescens</i>	0.001	50	7.08	0.006	0.002	0.008	0.002	0.010
<i>Zanthoxylum armatum</i>	0.033	150	10.18	0.050	0.032	0.082	0.154	0.236
Total	1.327	8800	300	3.107	1.665	4.772	4.131	8.903

Where: Site I- Grassland, Site II- Chir pine forest, Site III- Mixed forest, Site IV- Ban-oak forest and Site V- Deodar forest

Branch biomass (t/ha) of shrubs, in this site, varied from 0.114 (*M. africana*) to 5.664 (*I. gerardiana*). Leaf biomass was recorded highest 1.445 t/ha for *I. gerardiana* and lowest 0.015 t/ha for *H. helix*. Aboveground biomass of shrubs ranged from 0.139 (*M. africana*) to 7.119 (*I. gerardiana*) t/ha while belowground biomass varied from 0.018 (*H. helix*) to 1.955 (*I. gerardiana*) t/ha. Total biomass among shrubs was highest (9.073 t/ha) for *I. gerardiana* and lowest (0.070 t/ha) for *H. helix*

In site IV, at higher elevation, basal area in different shrubs fluctuated from 0.001 (*C. nepalensis*) 0.405 to (*B. lycium*)m²/ha. Their density ranged from 50 (*C. nepalensis*) to 800 m²/ha (*I. dosua*). *B. lycium* was the dominant shrub with maximum IVI value as 66.17 and *C. nepalensis* was the rare species with minimum IVI value (7.40).

Branch biomass values for different shrubs in site IV, ranged from 0.003 (*C. nepalensis*) to 0.957 (*I. gerardiana*) t/ha. Leaf biomass of shrubs species fluctuated between 0.187 (*I. gerardiana*) to 0.005 (*C. nepalensis*) t/ha. Aboveground biomass of shrubs showed that it was maximum (1.144 t/ha) for *I. gerardiana* and minimum (0.007 t/ha) for *C. nepalensis*. Likewise belowground biomass was maximum 0.584 t/ha for (*I. dosua*) and minimum 0.001 t/ha for *C. nepalensis*. Total biomass of individual shrub species ranged from 0.008 (*C. nepalensis*) to 1.428 (*I. gerardiana*) t/ha (Table 32).

The phytosociology of constituent shrubs, in site V, revealed that *M. africana* had highest (0.360 m²/ha) and *W. canescens* had lowest (0.001m²/ha) basal area. *M. africana* had highest density (2850 plants/ha) and *W. canescens* had lowest density of 50 plants/ha. *M. africana* was the dominant shrub with IVI as 72.99 and *P. utilis* and *S. saligna* were the co-dominant shrubs with IVI values as 64.27 and 57.36, respectively.

Branch biomass (t/ha) of constituent shrubs varied from 0.006 (*W. canescens*) to 0.931 (*B. lycium*). Leaf biomass was recorded highest for *P. utilis* (0.501 t/ha) and lowest for *W. canescens* (0.002 t/ha). Aboveground biomass of the individual shrubs ranged from 0.008 (*W.*

canescens) to 1.334 (*M. africana*) t/ha. Belowground biomass varied from 0.002 t/ha (*W. canescens*) to 1.960 t/ha (*M. africana*). Total biomass of the individual shrubs in this site fluctuated between 0.010 (*W. canescens*) to 3.294 (*M. africana*) t/ha. Maximum contribution to total biomass was by *M. africana* (37.0%) followed by *B.lycium* (23.70%) (Table 32).

Comparing the five sites at higher elevation, it was evident from the data in Table 32 that the density basal area and total biomass of shrubs was highest in site V.

Statistical analysis of data carried for grassland, mixed forest and chir pine forests at three elevations revealed that, density of shrubs increased in the order: grassland > mixed forest > chir pine forest. It was evident that density of shrubs was significantly higher at middle elevation. The effect of elevation on density of shrubs in grasslands revealed that it was minimum at middle elevation, which was statistically at par with lower elevation, however, maximum density was observed for higher elevation. In case of chir pine and mixed forests the density of shrubs was significantly higher at middle elevation (Table 33).

Table 33. Interaction between density of shrubs in different grassland/ forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	1900	2550	2200	2217
Middle (1300-1600)	1850	7150	6050	5017
Higher (1600 and above)	2050	2790	3600	2813
Mean	1933	4163	3950	

		SE _±	CD _{0.05}
T	=	47.14	99.93
F	=	47.14	99.93
TxF	=	81.62	173.03

Statistical analysis of data (Table 34) reveals that basal area of shrubs was significantly low in grasslands as compared to chir pine and mixed forests. In grassland and chir pine forest the basal area of shrubs was maximum at higher elevation which decreased with further decrease

in elevation. Whereas, in mixed forest, maximum basal area was recorded at middle elevation which was statistically at par with higher elevation. The effect of elevation on basal area revealed that, basal area of shrubs increased with increase in elevation.

Table 34. Interaction between basal area of shrubs in different grassland/ forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	0.31	0.27	0.62	0.40
Middle (1300-1600)	0.21	0.86	1.06	0.71
Higher (1600 and above)	0.54	0.99	0.97	0.83
Mean	0.35	0.71	0.88	

		SE $\pm$	CD _{0.05}
T	=	0.04	0.09
F	=	0.04	0.09
TxF	=	0.08	0.17

Further biomass of shrubs was significantly low in grasslands and chir pine forests as compared to mixed forests. The effect of elevation on biomass of shrubs in grasslands revealed that it was significantly higher at lower elevation. Whereas, in chir pine and mixed forests, biomass of shrubs increased significantly with the increase in elevation. Comparing different elevations, it was observed that biomass of shrubs increased with the increase in elevation (Table 35).

Table 35. Interaction between biomass of shrubs in different grassland/ forests (F) and elevations (T)

Elevation (T)	Grassland/Forest (F)			
	Grassland	Chir pine	Mixed	Mean
Lower (900-1300)	6.64	2.16	5.62	4.80
Middle (1300-1600)	2.20	5.74	7.20	5.04
Higher (1600 and above)	4.41	6.80	8.60	6.60
Mean	4.41	4.90	7.13	

		SE $\pm$	CD _{0.05}
T	=	0.03	0.07
F	=	0.03	0.07
TxF	=	0.05	0.11

Biomass of trees

Among the different elevation classes the maximum tree biomass (aboveground, belowground and total) was recorded at highest elevation class (Table 36). Comparing biomass production of different forests at lower elevation, mixed forest exhibited highest (238.48) total biomass followed by ban-oak (216.99) and least in chir pine forest (176.69). However, at middle elevation, it was observed that chir pine forest exhibited maximum biomass compared to mixed forest, At higher elevation, ban-oak forest showed highest biomass accumulation (409.57) followed by deodar (298.49), chir pine (289.57) and mixed forest (265.76).

Biomass under different forests/grasslands

The perusal of data in Table 37, indicated that highest biomass production occurred at lower elevation in mixed forest (252.84 t/ha) followed by ban-oak (223.52 t/ha) and chir pine (186.01 t/ha). At middle elevation total biomass production of chir pine forest (337.92 t/ha) exceeded mixed forest (224.66 t/ha). At higher elevation decreasing precedence of total biomass of forest was: ban-oak forest (421.49 t/ha) > deodar forest (311.80 t/ha) > chir pine forest (301.66 t/ha) > mixed forest (280.89 t/ha). The biomass at different elevations revealed that maximum biomass of forests occurred at middle elevation. Mixed and oak forests showed highest biomass at higher elevation. Biomass of grasslands (shrubs & herbs) was significantly low as compared to forests and ranged between 12.34 (higher elevation) to 16.26 t/ha (lower elevation).

Carbon stock of trees

The data pertaining to carbon stock of trees under different forests is given in Table 38. The data revealed that total carbon stock in different forests at lower elevation was in order: mixed forest > ban-oak forest > chir pine forest with respective values of carbon stock of trees 117.25 > 106.56 > 86.88 t/ha. At middle elevation the carbon stock in chir pine forest and mixed forest was recorded as: 160.35 and 102.03 t/ha,

Table 36: Above and belowground biomass (t/ha) of trees under different forests along different altitudinal ranges

Forests	900-1300m			1300-1600m			1600m and above		
	Aboveground biomass (A)	Belowground biomass (B)	Total biomass (A+B)	Aboveground biomass (A)	Belowground biomass (B)	Total biomass (A+B)	Aboveground biomass (A)	Belowground biomass (B)	Total biomass (A+B)
Chir pine	147.25	29.45	176.69	217.79	54.35	326.14	241.31	48.26	289.57
Mixed	198.74	39.74	238.48	172.94	34.58	207.52	221.47	44.29	265.76
Ban oak	178.32	38.67	216.99	-	-	-	341.35	68.26	409.57
Deodar	-	-	-	-	-	-	248.74	49.75	298.49

Table 37: Total biomass (t/ha) under different forests/grasslands along altitudinal ranges

Forests/ grasslands	900-1300m				1300-1600m				1600m and above			
	Herbs	Shrubs	Trees	Total	Herbs	Shrubs	Trees	Total	Herbs	Shrubs	Trees	Total
Grassland	9.62	6.64	-	16.26	11.13	2.20	-	13.33	7.93	4.41	-	12.34
Chir pine	7.16	2.16	176.69	186.01	6.05	5.74	326.14	337.92	5.29	6.80	289.57	301.66
Mixed	8.73	5.62	238.48	252.84	9.95	7.20	207.52	224.66	6.54	8.59	265.76	280.89
Ban oak	3.63	2.90	216.99	223.52	-	-	-	-	6.01	5.92	409.57	421.49
Deodar	-	-	-	-	-	-	-	-	4.41	8.90	298.49	311.80

Table 38: Carbon stock of trees (t/ha) under different forests along different altitudinal ranges

Forests	900-1300m			1300-1600m			1600m and above		
	Aboveground carbon stock (A)	Belowground carbon stock (B)	Total carbon stock (A+B)	Aboveground carbon stock (A)	Belowground carbon stock (B)	Total carbon stock (A+B)	Aboveground carbon stock (A)	Belowground carbon stock (B)	Total carbon stock (A+B)
Chir pine	73.63	13.25	86.88	135.90	24.46	160.35	120.66	21.72	142.37
Mixed	99.37	17.88	117.25	86.47	15.56	102.03	110.74	19.93	130.67
Ban oak	89.16	17.40	106.56	-	-	-	170.68	30.72	201.39
Deodar	-	-	-	-	-	-	124.37	22.39	146.76

respectively. At higher elevation carbon stock of ban-oak forest (201.39) was higher as compared to deodar forest (146.76), chir pine forest (142.37) and mixed forest (130.67). Carbon stock of chir pine forest increased with increase in elevation. Mixed and ban-oak forests showed highest carbon stock at higher elevation class.

Soil organic carbon (%) and Bulk density

Soil organic carbon and bulk densities at two soil depths i.e. 0-20 and 20-40cm under different forests and elevations are given in Table 39. Soil organic carbon (%) decreased with soil depth at all elevations. In open grasslands it ranged from 1.67% to 2.14% at 0-20cm depth and 1.15 to 1.98% at 0-40 cm depth at different elevation classes. Bulk density did not show any distinct trend with the depth of soil. In general, it was highest in grasslands followed by chir pine forests. It was recorded that bulk density of soil was inversely proportional to soil organic carbon (%). In grassland bulk density along altitudinal ranges varied from 0.994-1.200 in 0-20 cm depth and 1.000-1.352 in 20-40 cm depth.

Soil organic carbon (SOC)

Soil organic carbon (SOC) in the soil layer 0-20 and 20-40cm at lower elevation varied from 50.33-40.08 and 49.28-31.10 (t/ha), respectively. At middle elevation it ranged from 50.27-43.71 and 45.94-42.14 t/ha, respectively and at higher elevation from 54.51-42.54 and 51.04-39.60 t/ha, respectively (Table 40). Soil organic carbon in different forests followed the order: ban-oak forest > mixed forest > deodar forest > chir pine forest > grassland. SOC was recorded higher in 0-20 cm depth of soil as compared to 20-40 cm depth of soil. The variation in SOC of different forests/grasslands along altitudinal range did not reveal any significant trend.

Carbon Stock in different eco-system:

An overview of Table 41 shows the amount of carbon stock accumulation (t/ha) in different ecosystems. At lower elevation carbon

Table 39: Soil organic carbon (%) and bulk density (g cm⁻³) under different forests/grasslands along different altitudinal ranges

Forests/ grasslands	Organic carbon						Bulk density					
	900-1300m		1300-1600m		1600m and above		900-1300m		1300-1600m		1600m and above	
	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm
Grassland	1.67	1.15	2.12	1.74	2.14	1.98	1.200	1.352	1.031	1.211	0.994	1.000
Chir pine	2.20	1.95	2.44	2.09	2.88	2.56	1.088	1.137	1.001	1.099	0.875	0.900
Mixed	2.46	2.24	2.66	2.35	3.12	2.90	1.023	1.100	0.945	0.965	0.861	0.873
Ban oak	2.88	2.71	-	-	3.21	2.95	0.855	0.861	-	-	0.849	0.865
Deodar	-	-	-	-	3.01	2.84	-	-	-	-	0.880	0.891

Table 40: Soil organic carbon (t/ha) in different forests/grasslands along different altitudinal ranges

Forests/ grasslands	900-1300m		1300-1600m		1600m and above	
	0-20cm	20-40cm	0-20cm	20-40cm	0-20cm	20-40cm
Grassland	40.08	31.10	43.71	42.14	42.54	39.60
Chir pine	47.87	44.34	48.85	45.94	50.40	46.08
Mixed	50.33	49.28	50.27	45.36	53.73	50.63
Ban oak	49.25	46.67	-	-	54.51	51.04
Deodar	-	-	-	-	52.98	50.61

Table 41: Carbon stock (t/ha) in different ecosystem

Ecosystem	Herbs	Shrubs	Trees	Soil (0-40cm)	Total
900-1300m					
Grassland	4.33	2.99	-	71.18	78.50
Chir pine	3.22	0.97	86.88	92.22	183.29
Mixed	3.93	2.53	117.25	99.61	223.32
Ban-oak	1.63	1.31	106.56	95.91	205.41
1300-1600m					
Grassland	5.00	0.99	-	85.86	91.85
Chir pine	2.72	2.58	160.35	94.79	260.44
Mixed	4.48	3.24	102.03	95.63	205.38
1600m and above					
Grassland	3.57	1.99	-	82.14	87.70
Chir pine	2.38	3.06	142.37	96.48	244.29
Mixed	2.94	3.87	130.67	104.36	241.84
Ban-oak	2.70	2.66	201.39	105.54	312.29
Deodar	4.41	4.01	146.76	103.58	258.76

stock in different forests/grassland followed the precedence: mixed forest (223.32) > ban-oak forest (205.41) > chir pine forest (183.29) > grassland (78.50), at middle elevation: chir pine forest (260.44) > mixed forest (205.38) > grassland (91.85) and at higher elevation: ban-oak forest (312.29) > deodar forest (258.76) > chir pine forest (244.29) > mixed forest (241.84) > grassland (87.70). Among different chir pine forests, highest carbon stock (t/ha) was exhibited in middle elevation 260.44 followed by higher elevation 244.29 and minimum in lower elevation 223.32 (t/ha). Comparing mixed forests of different elevations, maximum carbon stock was recorded in higher elevation 241.84 t/ha followed by lower elevation 223.32 t/ha and least in middle elevation 205.38 t/ha. Similarly, carbon stock in ban-oak forest at lower elevation was 205.41 t/ha which increased with the increase in elevation to 312.29 t/ha at higher elevation. Carbon stock in deodar forest was 258.76 t/ha.

Chapter-5

DISCUSSION

Socio-economic status

The exploitation of natural resources in any area depends on population size and its distribution in the area. Wide variations in the population density among villages noticed in the current micro-watershed suggest that the people have tried to concentrate around the lower elevation, due to better linkage of these villages to satellite towns and facilities like drinking water, transportation and road infrastructure etc. Also the slope of the land is gentle in lower elevation which is suitable for cultivation of agriculture crops. The population density (Fig.5) of the study area ($219/\text{km}^2$) was higher than the state's population density ($109/\text{km}^2$). Population density was higher in village Bagaur as people living here are employed in nearby university (Fig.4). Higher population density of the micro-watershed was due to settlement of many workers in this region who are employed in nearby town. The excessive demographic pressure in the area also mean that food security, a high standard of living and respect for the environment is at stress or risk due to more demand from natural resources. It is pertinent that demand is a product of population and per capita consumption that result in over exploitation of resources. Further, a decreasing return per unit of effort takes place when an intensification of exploitation of natural resources occurs (Mario and David, 1994).

The average gender ratio of the villages in the watershed is 961 female per 1,000 males which is higher when compared to the gender ratio of state (Himachal Pradesh), which is considered as female deficit state. The good gender ratio in the micro-watershed perhaps reveals the importance given to females to do various day to day activities. Females in this watershed are actively engaged in agriculture besides looking after

their homes. There were 17 villages which had less number of female population (Fig.6). In only six villages of the micro-watershed less female per 1000 male ratio was recorded as compared to average value for state (Fig.7). The literacy rate of micro-watershed was 85% which was higher when compared to state literacy rate 76.48%. High literacy rate in the micro-watershed has encouraged outflow of males to cities in search of employment which has its impact on gender ratio too.

The plant species like *G. optiva*, *B. variegata*, *C. australis*, *L. leucocephala* and *Q. leucotrichophora* grow throughout the sub-tropical zone of Solan district and are commonly used as fodder for animals in this micro-watershed. These species are rich in crude protein and fiber, which helps in increasing the quantity of milk and animal health beside prime fodder species during the lean season. Average fuelwood consumption by a household was 12.5 kg/day, which is similar to results reported by Chandra (2008) in Arnigad watershed in Uttarakhand, Bhatt *et al.* (1994) in Western Himalayas and Mahat *et al.* (1987) for Himalayan range.

Floristic composition

The natural course of plant cover development in any area is manifestation of ecological and anthropogenic factors prevailing there. The present study conducted in nine forests beside three grasslands located at lower (900-1300 m), middle (1300-1600 m) and higher (1600 m and above) elevation classes in subtropical regions of H.P, revealed that the generic spectrum comprised of 79 genera with 87 species of trees, shrubs and herbs. Most of the forests in the present study were pure forests except for mixed forests where three tree species were recorded at each elevation class. Tree species primarily belonged to Pinaceae and Fagaceae shrubs to Verbenaceae, Rosaceae, leguminosae and Labiateae whereas, herbaceous flora primarily belonged to Poaceae, Cyperaceae and Leguminosae. Comparing floristic composition of different forests/grasslands at three elevations, it was observed that at

lower elevation species number varied from 21-30, at middle elevation 22-37 and at higher elevation 22-33 (Table 2).

The number of shrubs species in forests varied from 7-10 in lower elevation, 7-15 at middle elevation while at higher elevation it ranged from 9-12, whereas in grasslands at different elevations shrub number varied from 7-9 (Table 2). Types of shrubs reported in the present forest sites are similar to findings of Gupta (2001) for Nauli area of Solan and Thakur *et al.* (2008) for Kuthar range of Kunihar Forest Division Solan. At three elevations among herbs number of grasses (10-14 species) were far more as compared to legumes (1-3), sedges (1-3) or forbs (1-7). The number of shrubs and herbs species in grasslands and different forests, in general, did not vary much showing trees have little effect on floristic composition of herbaceous vegetation. Many workers Dass (1995), Guleria *et al.* (1999¹), Sah (2002), Dutt and Gupta (2005¹), Mahmoud (2009) has also reported dominance of grasses in herbaceous vegetation in various forests of Solan (H P).

The type of tree species did affect the ground flora. In oak forest herb species were distinctly different from mixed and chir pine forests. In deodar forest low number of grasses and higher number of forbs were recorded, which is different from other forests. Low grass species may be characteristic of deodar forests as also reported by Singh and Gupta, (2009). Common plant species among different experimental sites at three elevations were: *Q. leucotricophora*, *P. roxburghii*, *C. carandus*, *L. camara*, *W. fruticosa*, *B. lycium*, *C. wallichiana*, *M. africana*, *C. montanus*, *H. contortus*, *T. anathera*, *D. annulatum*, *A. mutica* and *P. maximum*. Various workers viz., Sah (2002), Dutt and Gupta (2005¹), Bahar (2003), Gupta *et al.* (2002), Mahmoud (2009) and Kumar (2009) has also reported these species in their studies on vegetation of Solan area.

A characteristic of mountain ecosystems is that elevation gradients create varied climates, along with resultant soil differentiation, promote the diversification of plant species (Brown, 2001; Lomolino, 2001,

Camarero and Gutiérrez 2002). The regional patterns of species richness are a consequence of many interacting factors, such as plant productivity, competition, geographical area, regional species dynamics, regional species pool, environmental variables and human activity (Woodward, 1988; Palmer, 1991; Eriksson, 1996; Zobel, 1997; Criddle *et al.*, 2003). In the present study no perceptible change in plant diversity along altitudinal gradient was observed though many species recorded in oak and deodar forests at upper elevation were not present in the middle or lower elevation. The distribution of species did not follow any pattern as explained by Rahbek (1995,1997) for mountain ecosystems i.e., a monotonic decline in species richness from low to high elevation, a hump-shaped pattern with a maximum at mid-elevations, or essentially a constant from the lowlands to mid-elevations followed by a strong decline further up.

Phytosociology

Growth attributes i.e. density and basal area of herbage showed consistent rise from July with advancement of growing season and attained peak values in August/September and decreased thereafter. This trend followed the rainfall pattern as monthly rainfall in this area increased till September before declining in October (Fig.1). Sequel to sporadic germination and development of herbage with the onset of monsoon in July, the density and basal area of herbage increased up to September which can be ascribed to congenial growth conditions in term of nutrient availability, soil moisture, humidity and temperature. Similar pattern of variations in density and basal area of herbage along growing season with its dependence on rainfall pattern has been reported by Sundriyal *et al.* (1987), Singh and Yadava (1974), Trivedi (1994), Sah (2002), Guleria *et al.* (1999¹), Rao (1998), Dutt and Gupta (2005^{1&2}) for monsoonal grasslands, Mahmoud (2009) for chirpine forests and Kunhikannan (2008) for mixed forest.

Peak density (tillers/m²) and basal area (cm²/m²) of herbs at lower elevation in different forests varied from 639.32-826.88 and 24.96-55.45, respectively. At middle elevation density as well as basal area increased to 836.66-886.00 and 41.39-66.45, respectively whereas at higher elevation they were 301.68-992.01 and 25.98-37.40, respectively (Table 3-14). Density and basal area of herbage recorded in the present forests/grasslands are in the range as reported by other researchers for forests/grasslands of Solan region (Guleria *et al*, 1999¹; Dutt and Gupta, 2005^{1&2}; Thakur *et al.*, 2005; Gupta and Das, 2007; and Mahmoud, 2009) and other areas of HP (Rattan and Singh, 2009). At all the elevations herbage in the grassland exhibited higher density (tillers/m²) and basal area (cm²/m²) in comparison to forests with the values as 1195.70 & 98.23 at lower elevation, 1121.29 & 84.13 at middle elevation and 1360.00 & 50.38 at higher elevation, respectively. The decrease in density & basal area of herbage under trees can be related to low relative light intensity under trees (Ludwig *et al.*, 2004, Dutt and Gupta, 2005^{1&2}), allelopathic affect (Gupta *et al.*, 2007; Guevara-Escobar *et al.*, 2007; Mahmoud, 2009; Michael *et al.*, 2009; Benavides *et al.*, 2009 and Hussain *et al.*, 2009), microhabitat variation (Johnson, 1995), yearly variations in abiotic variables (Berg and Staaf, 1981) and microclimate modification (Anderson *et al.*, 1968). Low density and basal area under trees have been also reported by many other workers (Naugraiya and Pathak, 2001; Soni, 2001).

The values of density and basal area of herbage were appreciably low in ban-oak and deodar forests. The results show that these trees affected the growth of understorey vegetation more as compared to other trees. Allelochemicals are synthesized by plants, which are released into environment after decomposition. These allelochemicals play a great role in regulating patterns of vegetation, distribution of plants in communities and growth and development (Saxena and Sharma, 1996). *Quercus douglasii* has large amount of fibrous roots in upper layer of soil and much low pre-dawn xylem pressure potential which causes suppression of

herbage (Collaway *et al.*, 1991). Similar reasons can be attributed to low density and basal area of herbage under *Q. leucotrichophora* in the present study.

Comparatively higher value of growing attributes for only few grasses like *C. montanus*, *H. contortus*, *P. maximum*, *T. anathera*, and *A. mutica* in different forests reveal their better adaptation to prevailing conditions (Table 3-14). The dominance of few species in a plant community has also reported by Chaturvedi *et al.* (1988), Rao (1998), Bawa (1986), Kapoor (1987), Kumar (2001), Dutt and Gupta (2005¹ &²), Thakur *et al.* (2005), Kumar (2009) and Mahmoud (2009) for different plant communities.

Based on the dominant species the herbaceous communities in different forests/grasslands (Tables 3-14) can be christened as: *Chrysopogon-Heteropogon* (grassland, Site-I), *Themeda-Chrysopogon-Arundinella* (chir pine forest, Site-II), *Chrysopogon-Heteropogon* (mixed forest, Site-III), *Arundinella-Chrysopogon-Themeda* (ban-oak forest, Site-IV) at lower elevation, whereas at middle elevation *Chrysopogon-Heteropogon* (grassland, Site-I), *Themeda-Arundinella* (chir pine forest, Site-II), *Chrysopogon-Themeda* (mixed forest, Site-III). The herbage communities at higher elevation can be named as: *Themeda-Panicum* (grassland Site-I), *Themeda-Arundinella* (chir pine Site-II), *Chrysopogon-Panicum* (mixed Site-III), *Themeda-Apluda-Chrysopogon* (ban-oak forest, Site-IV) and *Cyperus-Carex* (deodar forest, Site-V).

Density (stem/ha) and basal area (m²/ha) of shrubs was high under different forests as compared to grasslands at three elevations. The results suggest that trees have favored the growth of shrubs. It was further recorded that density and basal area of shrubs increased with increase in elevation. Density and basal area of shrubs varied in forests from 2200-6866 and 0.272-0.624, respectively at lower elevation, 6050-7150 and 0.863-1.056, respectively at middle elevation whereas at higher elevation 2790-8800 and 0.896-1.327, respectively. In grasslands, density

and basal area of shrubs at lower, middle and higher elevation was: 1900 & 0.311, 1850 & 0.216, 2050 & 0.537, respectively (Table 30-32).

Among the different forests the density of shrubs was highest in deodar forest. Singh and Gupta (2009) also reported similar range of density and basal area of shrubs in deodar forests of Kothi in Shimla. Shrubs are efficient nutrient absorbers due to their high root to shoot ratio (Maithani *et al.*, 1988) and shallow root system with profuse distribution of roots in upper horizon of soil. Due to these properties they can establish themselves in any moisture and nutrient gradient. Thus, in the present study the density and basal area of shrubs varied among forests at different elevations due to the differences in microclimate under trees in different forests and their adaptability to the microclimate. However, shrubs showed better growth attributes at higher elevation.

Biomass of herbs and shrubs

The biomass of herbage increased from July onwards till September. This may be related to spurt of growth with the advent of monsoon in July resulting from better growing conditions like high relative humidity and soil moisture during growing period. Thus enough soil moisture availability for optimum nutrient flow in soil-plant system and congenial air temperature manifested itself into luxurious vegetative growth of plants, accompanied by their enhanced tillering and basal area. Similar role of climatic variables on growth and development of herbage vegetation has been advocated by Sundriya *et al.* (1987), Singh and Yadava (1974), Singh and Joshi (1979), Trivedi (1994), Dass (1995), Guleria *et al.* (1999²), Dalai (1997), Rao *et al.* (1998), Kumar (2001), Sah (2002), Dutt and Gupta (2005³), Kunhikannan (2008) and Mahmoud (2009).

Peak values of total above ground biomass of herbage (t/ha) in forests varied from 1.581-4.728 at lower elevation, 3.304-4.305 at middle elevation and 1.931-2.938 at higher elevation, whereas in grasslands at

three elevations viz. lower, middle and higher elevations peak aboveground biomass was 4.220, 5.581 and 3.534 t/ha respectively. In general, grassland recorded highest biomass of herbage at each elevation compared to forests (Table 17-28). Least aboveground biomass was recorded in oak forests at lower elevation. Similar biomass production of grasslands have been reported by, Dalai (1997), Rao *et al.* (1998), Guleria *et al.* (1999²), Gupta *et al.* (2002), Dutt and Gupta (2005³) and Mahmoud (2009) for Solan region. Reduction of light intensity under tree crown has been held as main factor for low production of herbage under trees by Grelen and Whrey (1978), Singh *et al.* (1980), Ramakrishna (1984), Hazra and Patil (1986), Chaturvedi *et al.* (1988) Bhatt *et al.*, (1994), Sharma and Dhiman (1994) and Dutt and Gupta (2005³). Allelopathy and interference of needle in chirpine has been advocated for low herbage production under trees by Gupta *et al.* (2007). Presence of fine roots upto 50 cm. of soil and much low pre-dawn xylem pressure potential as well as allelopathic effect on grassland productivity in blue-oak forest has been reported by Callaway *et al.* (1991).

Total biomass (t/ha) of shrubs at lower elevation varied from 2.164-6.637 and with the increase in elevation the shrub biomass also showed significant increase from 2.199-7.196 at middle elevation and 4.412-8.590 at high elevation (Table 30-32). As compared to other forests, shrub biomass in deodar forest was highest. Gradual increase in biomass at middle and higher elevation in the present study can be related to the increase in density of shrubs along elevation gradient. Likewise highest biomass of shrubs under *Cedrus deodara* forest can be related to highest density and basal area of shrubs among different forests/grasslands.

Biomass of trees

Total biomass of trees in different forests at lower elevation showed the precedence: mixed forest > ban-oak forest > chir pine forest, at middle elevation chir pine forest > mixed forest and at higher elevation ban-oak forest > deodar forest > chir pine forest > mixed forest. These

differences in tree biomass in different forests are a manifestation of inherent growth characteristic of trees beside the differences in density of trees. Comparing chir pine forest at different elevations highest production of trees was noted at middle elevation (1300-1600m) though the chir pine grows from 500-2100m (Singh and Singh, 1987). The present study suggests that best condition for growth and development of chir pine are available between 1300-1600m. Tiwari *et al.* (2005) has given similar biomass production for chir pine and mixed forests in North Western Himalayas as 174.16 t/ha and 259.28 t/ha, respectively. The difference in tree biomass of mixed forests at different elevations was partially due difference in tree species, at lower elevation *Q. leucotrichophora*, *E. tereticornis*, *A. mollissima* were present, at middle elevation *P. roxburghii*, *G. optiva* and *T. ciliata* species were recorded and at higher elevation *C. deodara*, *Q. leucotrichophora* and *P. roxburghii* species were present. In ban-oak forest the tree biomass increased appreciably as we moved from lower elevation to higher elevation. The natural habitat of the oak forests is above 1700m in Himalayan region thus higher biomass of ban-oak forest was recorded at higher elevation though the difference in density of trees at different elevations can also be accounted for difference in biomass. The present estimates of the biomass of forests in the present study (Table 36) are in the range of estimates given to similar forests of Central Himalaya i.e.163-787 t/ha and falls within the range of 200-600 t/ha given for many mature forests of the tropical world (Singh and Singh, 1987). Biomass production of ban-oak forests reported by Tiwari *et al.* (2005) for North Western Himalayas is also similar to present finding.

Soil organic carbon

The soil organic carbon (%) was higher at 0-20 cm as compared to 20-40 cm depth. Leaf litter accumulation on the surface and its decomposition with time enrich the upper layer continuously. Decrease in soil organic carbon with depth has been reported by Ramachandran *et al.* (2007) in Kolli hills in Eastern Ghats, Kumar (2003), Minj (2008), Goswami (2009) in Solan, Shiekh *et al.* 2009 for Garhwal Himalaya, Dinakaran

and Krishnayya (2008) for tropical soils and Alamgir & Amin (2008) for Chittagong (south) Forest Division, Bangladesh.

Organic carbon and bulk density of soil in grasslands varied from 1.67 to 2.14 % and 0.994 to 1.200 g cm⁻³, respectively in upper layer of soil (0-20 cm) which was low as compared to soils in different forests. High soil organic carbon under tree based system can be attributed to increased accumulation and decomposition of litter under trees as compared to grasslands (Kater *et al.*, 1992; Campbell *et al.*, 1994). Further, in the present study soil organic carbon ranged from 2.14%-3.21% in different forests in 0-20cm soil depth and 1.95% to 2.95% in 20-40cm soil depth. These values are slightly low as compared to figures reported for soils of similar forests in Garhwal Himalaya by Shiekh *et al.* (2009) and Singh (2009) but the values of soil organic carbon in *P. roxburghii* forests of present study were slightly higher than their finding for similar forests.

Soil organic carbon and bulk density differed markedly with forests. It was noticed that with the increase in elevation soil organic carbon also increased whereas bulk density showed reverse pattern. Similar results were noticed by Minhas (1986), Sharma (1991), Kaushal (1992) and Malik (1992), Singh (2008) and Singh 2009 in soils of Solan Forest Division of H.P. Further, with the increase in soil depth the organic carbon content also decreased in soil at all elevations whereas the bulk density increased markedly. Similar finding was reported by Minhas *et al.* (1997), Kumar (2003), Minj (2008) and Goswami (2009) for the soils of Solan (HP).

Soils in ban-oak forests had highest organic carbon, whereas, least was in chil forests (Table 38). Ban-oak forest exhibit high decomposition rate and rapid turnover of nutrient (Gupta and Larson, 1979). Relatively better conditions under ban-oak may be attributed to its close canopy (Saxena, 1979), more moist condition (Saxena and Singh, 1980) and fire free forest (Champion and Seth, 1968) while chil forest is relatively xeric, has recurring fire and slow rate of litter decomposition (Singh and

Singh, 1987) which attributed to low carbon in the soil. Bulk density was high in chil forests which may be due to low organic carbon which has positive correlation with pore space and negative correlation with bulk density (Bargali *et al.*, 1993).

Carbon stock

Carbon stock in the soil was higher in 0-20cm and compared to 0-40cm depth (Table 39). It is a function of organic carbon percent in soil, higher soil organic carbon in the soil at 0-20cm depth was responsible for higher carbon stock in 0-20 cm soil. The values recorded for carbon stock in the soils of chir pine plantation in present study correspond to the values given by Chauhan *et al.* (2004) for *P. roxburghii* forests of Dehradun, India. The carbon stock in the soil was found to increase with increase in elevation class which is in contrast to the finding of Shiekh *et al.* (2009) for the forests at different elevations in Garhwal Himalaya.

Carbon stock in forests was approximately three times as compared to grasslands at all elevations. Sanneh (2007) reported maximum carbon stock in forest land use, which was three times higher than the other perennial plant based system and eight times higher the annual production system. Singh (2008) and Sharma (2009) have also reported similar findings in Solan Forest Division. Carbon stock in ban-oak forest at higher elevation was highest. At lower elevation carbon stock in forests varied from 86.88 to 117.25 t/ha, while at middle elevation 102.03 to 160.35 t/ha and at higher elevation 130.67 to 201.39 t/ha. As per the estimates given by Gibbs *et al.* (2007) these values are higher than the values given for tropical dry forests (78-96 t/ha) of tropical Asia by IPCC (2006) but these values do correspond to the values given for tropical seasonal forests (105-169 t/ha). Houghton (1999) and DeFries *et al.* (2002) has given carbon stock estimates of tropical seasonal forests and tropical dry forests of tropical Asia as 250t/ha and 150t/ha, respectively that correspond to our estimates. According to one estimate the biomass for the forest cover of Himachal Pradesh (India) in 1994 has been

estimated as 85.01t/ha (Anon., 2002) while Manhas *et al.* (2006) has estimated carbon stock in conifers of temperate region in India between 28.88 to 65.21 t/ha, these estimates are less than the present findings (Table 37).

The carbon stock retained by different forests at lower elevation was in order: mixed forest > ban-oak forest > chir pine forest, at middle elevation chir pine forest > mixed forest, while as at higher elevation ban-oak forest > deodar forest > chir pine forest > mixed forest. Singh (2008) also reported the similar results in Solan Forest Division. The variation in carbon stock of forests is primarily regulated by their production potential and area under each of them (Table 40). Nazami *et al.* (2009) has contended that carbon stock in *P. roxburghii* forests of Pakistan range between 99 to 126 t/ha.

Chapter-6

SUMMARY AND CONCLUSION

The work done on “**Vegetation dynamics and land use cover of ‘Ga3a’ micro-watershed of Giri river in Solan district of Himachal Pradesh, India**” is summarized as below:

Socio economic status

Total number of villages in “Ga3a” micro-watershed was 37 and total population in them is 4615. Population density of micro-watershed is 219/km². Nine villages in the micro-watershed have less population density as compared to population density of Himachal Pradesh. The average sex ratio (female per 1000 male) of the villages in the micro-watershed is higher than sex ratio of the state. Six villages have less number of female per 1000 male than reported for Himachal Pradesh. Literacy rate in micro-watershed is 85%.

Delineation of Forests

Toposheet (53 F/1) in the scale 1:50000 was acquired from Forest Survey of India and contours on it were digitized at 20m interval using CARTALINX 2.1 data builder. Vector data so obtained was processed in IDRISI Taiga to produce Digital Elevation Model (DEM) of the area. It was stratified into three elevation classes viz. lower elevation (900-1300m), middle elevation (1300-1600m) and higher elevation (1600m and above). 57.53% area of the watershed falls under lower elevation class, 26.40% under middle elevation class and 16.06% under higher elevation class. The higher and middle elevations of the micro-watershed have steep slopes and in lower elevation gentle slopes were recorded. NE and NW aspects of the micro-watershed accounted for 27.94% area. Stockmap of Solan Forest Division was digitized and overlaid on re-classed DEM to identify forests at different elevation classes in the micro-watershed. At

lower elevation chir pine, ban-oak and mixed forests were identified. At middle elevation chir pine and mixed forests were recognized and at higher elevation chir pine forest, ban-oak forest, mixed forest and deodar forest were present. At each elevation one grassland site was also selected to study its vegetation composition.

Floristic composition

In all, 79 genera and 87 species were present in the micro-watershed. At lower, middle and higher elevation, total number of plant species (trees + shrubs + herbs) recorded were: 54, 51 and 54, respectively. This includes 7 trees, 35 shrubs and 45 herbs. Among herbs, 4 legumes, 5 sedges and 13 forbs were recorded. Floristic composition of vegetation in study sites at three elevations was almost same. The common trees, shrubs and herbs in these study sites were: *P. roxburghii*, *Q. leucotrichophora*, *C. microphylla*, *I. gerardiana*, *O. arborea*, *W. fruticosa*, *B. lycium*, *H. suaveolens*, *P. pashia*, *R. moschata*, *A. adscendens*, *M. africana*, *R. ellipticus*, *A. mutica*, *A. nepalensis*, *C. montanus*, *C. fulvus*, *D. annulatum*, *D. sanguinalis*, *H. contortus*, *P. maximum*, *R. exaltata*, *T. anathera*, *U. panicoides*, *S. glauca*, *C. mimosoides*, *D. floribundum*, *L. gerardiana*, *C. wallichiana* and *C. rotundus*.

Phytosociology and biomass of herbage and shrubs

Density, basal area and biomass of herbage were higher in grassland as compared to forests at all the three elevations. These parameters of vegetation increased consistently from July with onset of growing season and attained peak values in August/September and decreased thereafter. Density (tillers/m²) of herbage ranged from 1121.3 to 1360.0 in grasslands and 301.68 to 992.01 in forests. Likewise, basal area (cm²/m²) of herbage in grasslands and forests ranged from 50.38 to 98.23 and 24.96 to 55.45, respectively whereas above and belowground

biomass of herbage in grasslands and forests varied from 3.534 to 5.581 and 4.393 to 5.545 t/ha, respectively.

Density (m^2/ha) and basal area (plants/ha) of shrubs was higher under different forests as compared to grasslands at three elevations. The density and basal area of shrubs in grasslands ranged from 1850 to 2050 and 0.216 to 0.537, respectively and in forests from 2200 to 8800 to 0.272 to 1.327, respectively. Biomass of shrubs in grasslands and forests ranged from 2.199 to 6.637 and 2.164 to 8.903 t/ha, respectively. It was further recorded that density and basal area of shrubs increased with increase in elevation. Among the different forests density, basal area and biomass of shrubs was highest in deodar forest.

Based on dominance of different herbaceous species the herbage plant communities in different forests/grasslands were named as: *Chrysopogon-Heteropogon* (grassland, Site-I), *Themeda-Chrysopogon-Arundinella* (chir pine forest, Site-II), *Chrysopogon-Heteropogon* (mixed forest, Site-III), *Arundinella-Chrysopogon-Themeda* (ban-oak forest, Site-IV) at lower elevation, whereas at middle elevation *Chrysopogon-Heteropogon* (grassland, Site-I), *Themeda-Arundinella* (chir pine forest, Site-II), *Chrysopogon-Themeda* (mixed forest, Site-III). The herbage communities at higher elevation can be named as: *Themeda-Panicum* (grassland Site-I), *Themeda-Arundinella* (chir pine forest Site-II), *Chrysopogon-Panicum* (mixed Site-III), *Themeda-Apluda-Chrysopogon* (ban-oak forest, Site-IV) and *Cyperus-Carex* (deodar forest, Site-V).

Biomass of trees

The biomass of trees, in general, increased with the increase in elevation. Total biomass of trees in different forests at lower elevation showed the precedence: mixed forest (238.48 t/ha) > ban-oak forest (216.99 t/ha) > chir pine forest (176.69 t/ha), at middle elevation chir pine forest (326.14 t/ha) > mixed forest (207.52 t/ha) and at higher elevation

ban-oak forest (409.57 t/ha) > deodar forest (298.49 t/ha) > chir pine forest (289.57 t/ha) > mixed forest (265.76 t/ha).

Carbon inventory

Carbon stock of trees varied with elevation and forest type. At lower elevation, highest carbon stock was 117.25 t/ha in mixed forest, at middle elevation 160.35 t/ha in chir pine forest and at higher elevation 201.39 t/ha in ban-oak forest. The lowest carbon stock at respective elevations i.e. lower, middle and higher elevation was 86.88 t/ha (chir pine), 102.03 t/ha (mixed forest) and 130.67 t/ha (mixed forest).

Soil organic carbon(%) was higher in 0-20 cm depth as compared to 20-40 cm depth of soil at all elevations and study sites. However SOC (%) showed increasing trend with elevation, while bulk density was vice-versa. Soil organic carbon in different forests followed the order: ban-oak forest > mixed forest > deodar forest > chir pine forest > grassland.

Carbon stock accumulation in different study sites at lower elevation followed the order: mixed forest (223.21t/ha) > ban-oak forest (205.42 t/ha) > chir pine forest (183.17 t/ha) > grassland (70.24 t/ha), at middle elevation: chir pine forest (260.23 t/ha) > mixed forest (205.19 t/ha) > grassland (91.62 t/ha) and at higher elevation: ban-oak forest (312.13 t/ha) > deodar forest (258.58 t/ha) > chir pine forest (244.11 t/ha) > mixed forest (241.66 t/ha) > grassland (85.59 t/ha). Maximum carbon stock was present in ban-oak forest at higher elevation.

CONCLUSIONS

- The population density (219/km²) in the micro-watershed is slightly higher which may put more pressure on natural resources especially fuel wood requirement. But the higher literacy rate somehow may decrease this requirement as many habitants from here may migrate to cities in search of job.

- The gender ratio (961 female per thousand male) is better in the micro-watershed which is good for the society.
- The micro-watershed has gentle slope in the lower elevation which covers its 57.53% area that provides enough opportunities for intensive agriculture.
- The micro-watershed is rich in flora. 79 genera with 87 species were recorded in the present study. Graminaceous plants were more in number compared to others.
- The forest types in the micro-watershed are: chir pine, ban-oak, deodar and mixed forests. Deodar is restricted to higher elevation in a small area.
- Grasslands are distributed throughout the micro-watershed. There was gradual increase in density, basal area and biomass of herbage with the onset of rains in July and peak values reached in August/September. The aboveground biomass production of grasslands ranged from 3.534 to 5.581 t/ha. It decreased with increase in elevation.
- The biomass production of trees was highest in ban-oak forest, which was followed by deodar, chir pine and mixed forests. Chir pine forests showed highest tree biomass at 1300-1600 m.
- Soil organic carbon and carbon stock was more in 0-20cm than 20-40 cm soil depth.
- Carbon stock of forests increased with increase in elevation. Chir pine forests had highest carbon stock at middle elevation. Ban-oak forest had highest carbon stock at higher elevation.

Chapter-7

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ABSTRACT

Present study was done in ‘Ga3a’ micro-watershed of Giri river located at 30° 50’ to 30° 53’ N latitudes and 77° 08’ to 77° 15’ E longitudes in Solan district of H.P. India”, with the aim to analyse its land use types through GIS and assess phytosociology, biomass and carbon stock of vegetation. Contours on toposheet in the scale 1:50000, acquired from Forest Survey of India, were digitized at 20m interval using CARTALINX 2.1 and the vector data so obtained was rasterised using IDRISI Taiga to produce Digital Elevation Model (DEM) of the area. It was stratified into three elevation classes viz. lower elevation (900-1300m), middle elevation (1300-1600m) and higher elevation (1600m and above). 57.13% area of the watershed falls under lower elevation class, 26.40% under middle elevation class and 16.06% under higher elevation class. Socio-economic data was acquired from each elevation class through field survey. Stock map of the area available with Forest department was also digitized to identify forests at different elevation classes. Structural and functional parameters of trees, shrubs and herbaceous vegetation in every forest was studied by laying three sample plots of 0.1 ha each. Forests identified at lower elevation were: chir pine, ban-oak and mixed forest. At middle elevation chir pine and mixed forests were recognized and at higher elevation four forests viz., chir pine, ban-oak, mixed and deodar were present. At each elevation one grassland site was also selected to study its vegetation composition. Population density in the micro-watershed was 219 km² which is higher than the average population density of HP. The gender ratio (961 female per thousand male) in the micro-watershed is better than HP, which is good for the society. In all, 79 genera with 87 plant species were recorded in the micro-watershed. The density, basal area and biomass of herbage vegetation under different forests/grasslands at all the elevations increased gradually with the onset of rainfall in July and attained their peak values by August/September. Trees adversely affected the density, basal area and biomass of herbage thus grassland at all elevations exhibited higher values of these parameters as compared to forests. Total biomass under forests/grasslands at lower elevation showed the precedence; mixed forest (252.80 t/ha) > ban-oak forest (223.50 t/ha) > chir pine forest (186.00 t/ha) > grassland (16.26 t/ha). At middle elevation: chir pine (337.90 t/ha) > mixed (224.70 t/ha) > grassland and at higher elevation; ban-oak (421.50 t/ha) > deodar forest (311.80 t/ha) > chir pine forest (301.70 t/ha) > grassland (12.34 t/ha). Carbon stock accumulation in different forests/grassland at lower elevation decreased in the order: mixed forest (223.21t/ha) > ban-oak forest (205.42 t/ha) > chir pine forest (183.17 t/ha) > grassland (70.24 t/ha), at middle elevation: chir pine forest (260.23 t/ha) > mixed forest (205.19 t/ha) > grassland (91.62 t/ha) and at higher elevation: ban-oak forest (312.13 t/ha) > deodar forest (258.58 t/ha) > chir pine forest (244.11 t/ha) > mixed forest (241.66 t/ha) > grassland (85.59 t/ha).

Signature of Major Advisor

Signature of student

Countersigned

**Professor and Head
Department of Silviculture and Agroforestry
Dr. Y. S. Parmar University of Horticulture and Forestry,
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APPENDIX-I

SOCIO-ECONOMIC SURVEY

TITLE OF RESEARCH

**Vegetation Dynamic and Land Use Cover of ‘Ga3a’ micro-watershed of Giri
River in Solan District of Himcahal Pradesh**

Name of the Student : Haseeb-ul-Rashid Masoodi
Admission Number : F-2007-23-M
Department : Silviculture and Agroforestry

SURVEY SCHEDULE

Name

Village

Block

Altitude/latitude

Communication Address

Age of the family head

Qualification

Occupation

Agriculture

Service

Labour

Business

Any other (Please specify)

Total land holding (bighas)

Owned land holding

Rented land holding

Source of Income (please specify)

House (Kachha/Pacca)

Value of the house

Any other farm building

Value of the farm building

Average annual family income: Less than 10000 ☐, 10000-25000 ☐

More than 25000 ☐ (Please specify)

Sources of income (% share to total income)

Distance of the house from main road

Type of infrastructural facilities available in the village (School ☐, Road ☐, Hospital ☐,
Veterinary facilities ☐, Drinking water ☐ etc

Nature of dependence of forest

.....

.....

Availability of grazing lands Yes/No

Ownership of grazing lands

(Government/Private/Community)

FAMILIES

Sr. No.	Relationship	Age (Years)	Sex (M/F)	Education
1.				
2.				
3.				
4.				
5.				
6.				

Primary = 1, Middle = 2, High School = 3, 10+2 = 5, Diploma = 6, Illiterate = 7

FOREST RESOURCE USE

Name of the fodder/fuelwood trees used for fodder collection	Season of collecting fodder	Amount of fodder collected on daily/month basis

Availability of tree fodder: Increasing/decreasing/same for the last 5 years..... ..

..... ..

Alternative sources (Please specify)

Fodder quantity from agricultural field (Yes/No)

Please specify the season and quantity available

Do you purchase grasses/fodder (Yes/No)

The source of purchase

Annual amount spent on purchase

ANIMAL HUSBANDRY

Particulars	Number	Age	Use	Income
Cows				
Buffaloes				
Sheep				
Goats				
Bullocks				
Horses/mules				
Any other				

Sale of animal products (Yes/No)

Income form the sale of animal products

Curriculum Vitae

Personal Profile

Name : Haseeb ul Rashid Masoodi
Father's Name : Dr Abdul Rashid Masoodi
Date of Birth : 13-09-1985
Sex : Male
Marital status : Unmarried
Nationality : Indian
Permanent Address : Iddgah, Srinagar, J&K
E-Mail : shuja_cooldude@yahoo.co.in
Category : General
Extra Curricular Activities : Debates, conferences, freelance journalism, Athletics
Proficiency in languages : English, Hindi and Urdu

Academic Qualifications

Examinations Passed	Year of Passing	University/ Board	Subjects
Higher Secondary	2002	JKBOSE	English, Physics, Chemistry & Biology
Graduation	2007	Dr. B. R. A. University, Agra	Forestry

Scholarship/Stipend/Fellowship/Any other financial assistance received during study period : Ministry of Higher Education

Haseeb ul Rashid Masoodi